Design and Fabrication of a Planar Goubau Line Antenna at GHz Frequency

A THESIS
SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

BACHELOR OF ELECTRONICS & TELE-COMMUNICATION ENGINEERING

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UNDER THE GUIDANCE OF
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Certificate

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This is to certify that the project report entitled "*Design and Fabrication of a Planar Goubau Line Antenna at GHz Frequency*" submitted by Shoaib Bhutia (Class Roll Number: 001910701071) and Chayan Talukder (Class Roll Number: 101210701052) for the partial fulfilment of the requirements for the degree of Bachelor of Engineering in Electronics and Tele-communication Engineering at Jadavpur University, is based on the assigned project work during the academic session 2022-23, under the guidance of Prof. Bhaskar Gupta from the Department of Electronics and Tele-communication Engineering at Jadavpur University, Kolkata, West Bengal, India.

Signature of the Project Supervisor

Signature of the Student (Shoaib)

Signature of the Student (Chayan)

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Lastly, we would thank our alma mater, Jadavpur University, for encouraging us to take up a Project that involves large scale research and related study.

ABSTRACT

This report deals with design and fabrication of planar Goubau line (PGL) antenna. In the design, planar Goubau line antennas are simulated with a variety of shapes and sizes by using software CST to get the corresponding frequency response or return loss with the frequency of occurrence of partial discharge (PD). Planar goubau line antenna is designed with the type of substrate FR4 (Epsilon = 4.3) of size of length of 70 mm, width 40 mm and thickness 1.6 mm. In the final results, antenna design that is suitable for PD measurement is obtained with bandwidth, return loss (RL), VSWR as antenna parameters.

INTRODUCTION

In our previous semester report we talked about Goubau Line Antenna and how the corresponding changes in the length of PGL can drastically affect the parameters (i.e. S11, radiation efficiency, VSWR, Z-Parameter, farfield plots etc.) Here in this report, we will be rectifying all the faults and errors we have made in our previous report to get more conscience and precise results. We will also be fabricating and measuring S11 value of PGL to study its partial discharge characteristics.

Detection of the existence of partial discharge is one of the most effective methods to monitor the condition of the insulation. PD detection and monitoring system for diagnosis of power apparatus has been developed. Partial discharge is causing the physical phenomena in various forms. One of the physical phenomena that occur is electromagnetic waves that propagates in all directions and can be detected using an antenna.

Planar Goubau Line (PGL) is one of many types of antennas. Earlier, PGL have been used to detect the evanescent electric field patterns around wave guides and antennas. PGL is usually used at microwave frequencies with a thickness of substrate is 500μm that often become a choice because it does not limit the ability of bandwidth in the measurement frequency range VNA (Vector Network Analyzer) up to 325 GHz.

MATERIAL SELECTION

Copper

Material properties:

It is well known that, copper, the natural occurring metal, is an excellent conductor of electricity. This is the most widely used material in RF and microwave electronics. The material properties of copper are presented below-

TABLE 1 Material properties of copper

Parameter	Value
Electronic mobility	$32\ cm^2\ V^{-1}\ s^{-1}$
Current density	$\sim 10^6\ A\ cm^{-1}$
Tensile strength	587 MPa
Thermal conductivity	$400\ W\ m^{-1}\ K^{-1}$
Density	$2700\ kg\ m^{-3}$

Behaviour in GHz frequency:

Though copper has high electrical conductivity in RF and microwave frequency, but it does not remain same at GHz frequency. The skin depth and conductivity of copper metal decrease at GHz frequency. Kinetic inductance of copper is much more than internal inductance and less than the ohmic resistance at low GHz frequencies (where $\omega\tau \ll 1$, ω is angular frequency and τ is relaxation time). At 6.45 GHz, $\omega\tau = 1$ for copper. Therefore, ohmic resistance is the dominant contribution to surface impedance of copper wire below 6.45 GHz frequency. Therefore, it is very difficult to design effective copper antennas at GHz. The decrease of skin depth and conductivity of conventional copper metal at GHz frequency leads to high propagation losses and hence degrade the radiation efficiency.

Graphene

Material properties:

Graphene was discovered by Novoselov et al. in 2004 using micro-mechanical cleavage technique. It is a two-dimensional mono layer of sp_2 -bonded carbon atoms arranged in a hexagonal honeycomb lattice. The spacing between two carbon atoms in graphene is 0.142 nm and an interplanar spacing of two graphene sheets in graphite is 0.335 nm. Graphene is a zero-overlap semimetal or zero-gap semiconductor with very high electrical conductivity. The properties of graphene are summarized in Table 2. Graphene nanoribbon (GNR) is narrow strip of graphene sheet. One dimensional GNR is formed by etching or patterning the graphene sheet along armchair or zigzag direction. Thus, GNRs are of two kinds, viz., armchair and zigzag. The electronic properties of GNRs are ruled by the widths and atomic geometry along the edges, namely, zigzag or armchair. GNRs with zigzag-shaped edges are all metallic, while GNRs with armchair-shaped edges, can behave either as metallic or as semiconducting materials by controlling their width or chirality.

TABLE 2 Material properties of graphene

Parameter	Value
Electronic mobility	$\sim 2 \times 10^5$ cm^2 V^{-1} s^{-1}
Current density	$\sim 10^9$ A cm^{-1}
Velocity of fermion (electron)	$\sim 10^6$ m s^{-1}
Thermal conductivity	~ 5000 W m^{-1} K^{-1}
Tensile strength	~ 1.5 Tpa
Breaking strength	42 N m^{-1}
Transparency	$\sim 97.7\%$
Elastic limit	$\sim 20\%$
Surface area	~ 2360 m^2 g^{-1}

Behaviour in GHz frequency:

The unique electronic, optical, mechanical, and thermal properties of graphene at GHz frequency open plethora of applications in many fields. The novel property of graphene at GHz frequency is the propagation of surface plasmon polariton wave. At GHz frequency, graphene can be modelled as an infinite thin conductive sheet with a complex surface conductivity. The surface conductivity is characterized by both intra-band and inter-band conductivity. The intra-band and inter-band contribution of graphene conductivity has been derived from Kubo formalism as –

$$\sigma_{int\ ra}(\omega, \mu_c, \tau, T) = -j\frac{e^2 k_B T}{\pi\hbar^2(\omega - j\tau^{-1})}\left[\frac{\mu_c}{k_B T} + 2\ln\left(e^{-\frac{\mu_c}{k_B T}+1}\right)\right]$$

$$\sigma_{int\ er}(\omega, \mu_c, \tau, T) = -\frac{je^2}{4\pi\hbar}\ln\left[\frac{2|\mu_c| - \hbar(\omega - j\tau^{-1})}{2|\mu_c| + \hbar(\omega - j\tau^{-1})}\right]$$

Where, $f_b(\varepsilon) = \left[e^{(\varepsilon-\mu_C)/k_BT} + 1\right]^{-1}$ is the Fermi-Dirac distribution, ω is the angular frequency, ε is the energy, j is the imaginary unit, μ_C is the chemical potentional, T is the temperature, k_B is the Botlzman Constant, e is the charge of an electron, τ is the relaxation time and $\hbar$ is reduced Planck's Constant.
The intra-band conductivity dominates over inter-band conductivity in low GHz frequency range. Moreover, at low GHz frequency, single graphene layer provides an inductive surface impedance when $\omega > \frac{1}{\tau}$. It should be noted that T = 300 K and τ = 0.5, is assumed in our work. Owing to support of low loss plasmonic resonance at GHz frequencies, the use of monolayer graphene and bilayer graphene for GHz antenna application has recently been explored. Furthermore, the surface conductivity of graphene can be controlled by means of electrostatic bias or chemical doping, which in turn tunes the properties of graphene GHz antennas.

CNT

Material properties:
CNT is discovered by Sumio Iijima in 1991. Rolling of the graphene sheet forms the CNT. CNTs have different structure and properties. These can be either single-walled or multiwalled. Single-walled CNTs are of three kinds such as zigzag CNT, armchair CNT, and chiral CNT. Zigzag CNTs are insulators, armchair CNTs are conductors and chiral CNTs are semiconductors. The properties of CNT are summarized in Table

TABLE 3 The material properties of CNT

Parameter	Value
Electronic mobility	8×10^4 cm^2 V^{-1} s^{-1}
Current density	~10^9 A cm^{-1}
Velocity of fermion (electron)	~10^6 m s^{-1}
Tensile strength	50–500 GPa
Thermal conductivity	3000 W m^{-1} K^{-1}
Surface area	387 m^2 g^{-1}

Behaviour in GHz frequency:
Unlike the ohmic resistance of a copper metal, the quantum resistance of CNT is not inversely proportional to the square of its radius and is much smaller than that of copper metal wire of same size in nanoscale. The quantum conductance of CNT may be approximated as

$$\sigma_c(\omega) = -j\frac{2e^2 v_F}{\pi\hbar^2 r(\omega - jv)}$$

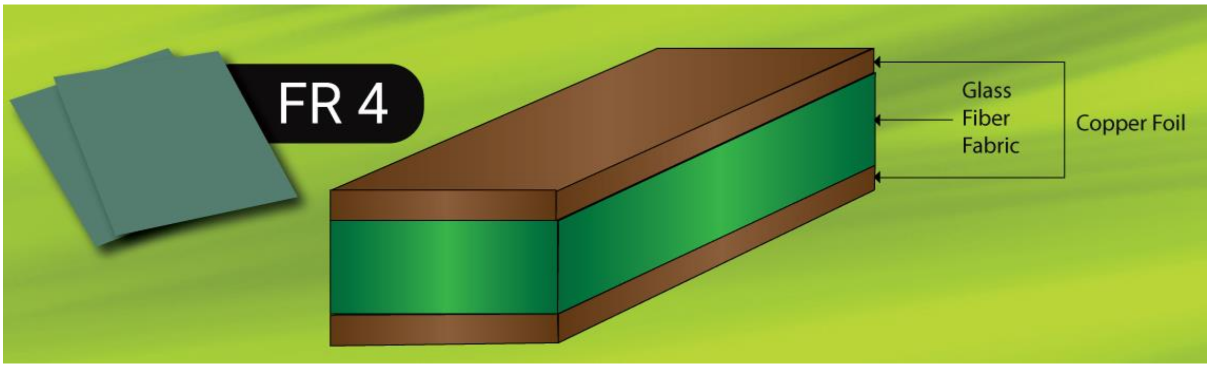
where r is radius of CNT, v and is the phenomenological relaxation frequency. Moreover, at GHz frequency, the skin effect in CNT can be ignored because of conduction of electron through p-bond of carbon atoms in CNTs. Thus, in case of CNT antenna, power dissipation is low, potentially leads to high antenna efficiency. Furthermore, CNT supports slow wave propagation, which enables high miniaturization compared to conventional copper antenna. Owing to excellent electrical and slow wave property, CNT can be the better material for GHz antennas compared to conventional metal GHz antennas.

We select Copper for our simulation and fabrication as it is readily available and in GHz Frequency there is not significantly higher difference in between CNT and Graphene. Although CNT is considered the best out of the three, the abundance and cost-effective Copper is used.

Substrate FR-4 (Epsilon = 4.3)

FR-4 is a widely used grade of flame-resistant, woven fiberglass-reinforced epoxy laminate material. It is a common choice for printed circuit board (PCB) substrates due to its excellent electrical insulation properties, high mechanical strength, and resistance to heat and flame. The name "FR-4" stands for "Flame Retardant 4," which indicates its ability to resist flame propagation. It is classified as a UL94V-0 material, meaning it meets the highest flammability rating set by Underwriters Laboratories (UL) for PCB materials. This classification ensures that FR-4 can withstand a high-temperature environment and will not contribute to the spread of fire.
FR-4 is composed of a woven fiberglass fabric impregnated with epoxy resin. The epoxy resin provides mechanical strength and electrical insulation, while the fiberglass reinforcement enhances the material's dimensional stability and overall rigidity. The combination of these properties makes FR-4 an ideal choice for PCBs, where it is used as a substrate to support and electrically isolate the electronic components.

One of the key advantages of FR-4 is its ability to withstand high operating temperatures. It typically has a glass transition temperature (Tg) of around 130-140°C, which means it remains mechanically stable and retains its electrical properties at elevated temperatures. This makes FR-4 suitable for applications that generate significant heat or operate in harsh environments. Furthermore, FR-4 offers good electrical insulation properties, allowing it to prevent electrical leakage or short circuits between conductive traces on the PCB. It also has low moisture absorption, which helps maintain the integrity of the PCB over time.



FR-4 is a common material for printed circuit boards (PCBs). A thin layer of copper foil is typically laminated to one or both sides of an FR-4 glass epoxy panel. These are commonly referred to as copper clad laminates. The copper thickness or copper weight can vary and so is specified separately. FR-4 is also used in the construction of relays, switches, standoffs, busbars, washers, arc shields, transformers and screw terminal strips.

We are using FR-4 as our substrate while making a G-Line Antenna. Although there are better choices like BCB or Rogers Compound for THz application, we are not bothered with them as in GHz application there is not much effect. FR-4 was easily available in our lab hence we picked it.

WHY ANISOTROPIC MATERIAL IS USED IN ANTENNA?

Anisotropic materials exhibit different electrical properties in different directions, such as varying permittivity or permeability. This characteristic allows for the design and control of antenna properties, including radiation pattern, polarization, and gain. By strategically using anisotropic materials, designers can tailor these properties to meet specific requirements. It can also be utilized to steer the radiation pattern of an antenna. By arranging the material in a particular manner, such as a phased array configuration, it is possible to control the direction of the emitted or received electromagnetic waves. This capability is crucial for applications like radar systems, satellite communications, and wireless communication networks. Furthermore, these materials can also enable the miniaturization of antennas. By exploiting the unique properties of anisotropic materials, engineers can achieve a more compact antenna design without sacrificing performance. This is particularly important in applications where size constraints exist, such as mobile devices, wearables, and unmanned aerial vehicles (UAVs).

Anisotropic materials can be used to manipulate the polarization of electromagnetic waves. By carefully selecting the orientation and properties of the anisotropic material, antenna designers can control the polarization characteristics of the antenna, allowing it to transmit or receive signals with specific polarization states. Also, it can help improve the bandwidth of an antenna. By using materials with specific anisotropic properties, such as frequency-dependent permittivity or permeability, it is possible to achieve a wider frequency range of operation for the antenna. This allows for better coverage and communication in diverse frequency bands.

SIGNIFICANCE OF COUPLERS IN G-LINE

The Goubau line is a transmission line that consists of a single wire surrounded by a dielectric material. It is used for guiding and propagating electromagnetic waves at microwave frequencies. However, for practical applications, it becomes necessary to efficiently couple the electromagnetic energy between the Goubau line and the surrounding free space.

The semi-circular plates, also known as flanges or horns, are placed on each side of the Goubau line to achieve this coupling. The purpose of these plates is to gradually transition the electromagnetic waves from the confined environment of the Goubau line to the open space, where the waves can radiate more freely. When the electromagnetic waves propagate along the Goubau line, they encounter the flanges. The flanges act as impedance transformers, gradually expanding the wavefront and matching the impedance of the Goubau line to that of free space. This expansion allows for a smoother transition of the electromagnetic waves into the surrounding space, reducing reflections and enhancing the radiation efficiency of the antenna.
Additionally, the semi-circular shape of the plates helps to reduce diffraction effects and provide a more directional radiation pattern. By carefully designing the dimensions and positioning of the flanges, the antenna's radiation efficiency can be controlled.

PROBLEMS AND ERRORS FACED IN PREVIOUS TRIALS

So we faced a lot of problems in our previous project like not having a good radiation efficiency (Coming down to as low -180dB from 0dB), almost straight S_{11} v/s frequency plot and even voltage standing wave ratio not staying between 1 and 2. These are not good for our antenna design. The main source of problems is mentioned below-

- Port attached to G-Line: We placed the port too far from the G-Line or attached the port along with the couplers. This resulted in the shorting of the couplers and hence G-Line simulation resulted in improper results.

- Dimensions of the port in CST: The port dimensions, when too small resulted in inconsistent result. We had to keep the dimensions to at least around 1.7(This was found out after multiple simulations, taking different port sizes into consideration) times the Port side of G-Line's Dimension for best results.

- Removing Ground Plane: Goubau line antennas do not require a conducting surface beneath them. The surrounding dielectric material acts as a supporting medium, allowing the surface waves to propagate.

- Changes in Materials: By Changing what material we use, we could drastically change our results. For high range of frequencies, we have used FR-4 Loss Free (from Rogers Compound), and Copper Annealed for our metal plates.

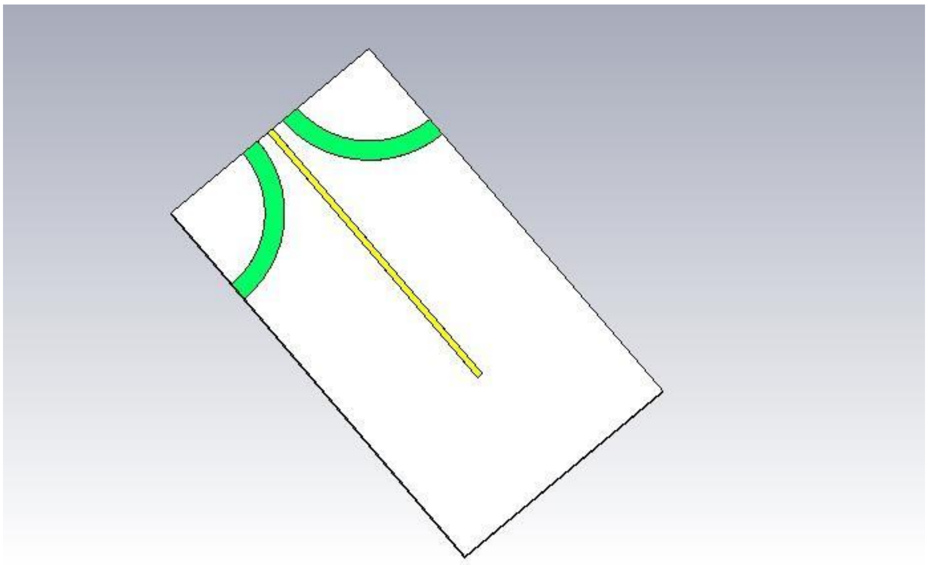
TRIAL 4:

Changes:

FR-4 (lossy)	→	FR-4(loss free)
Copper (pure)	→	Copper (annealed)

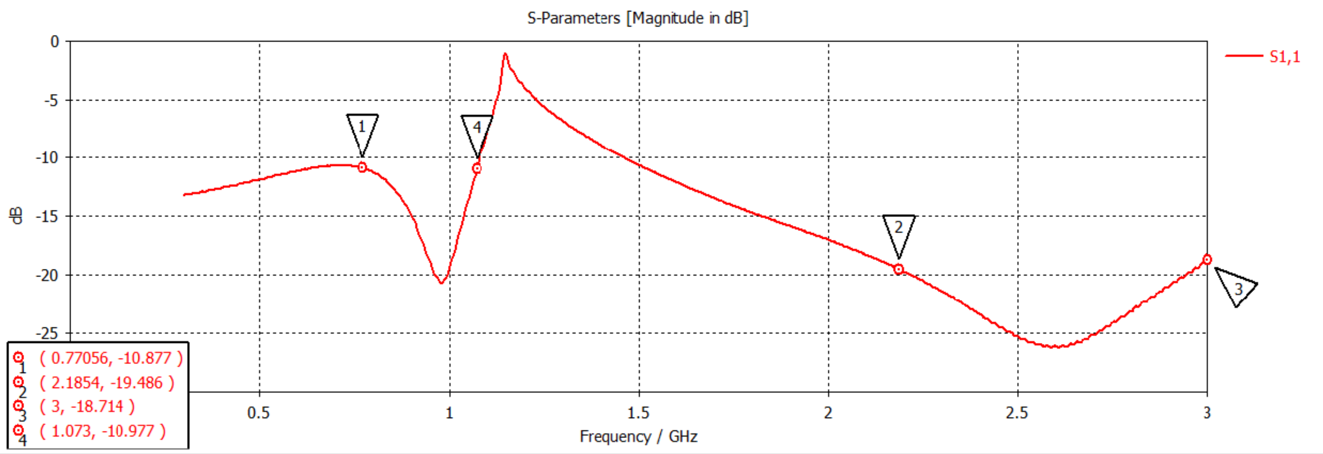
Port distance from the substrate I reduced down to 10mm. The previous 70mm port distance caused 'Transversal Open Boundary' error.

MODEL:

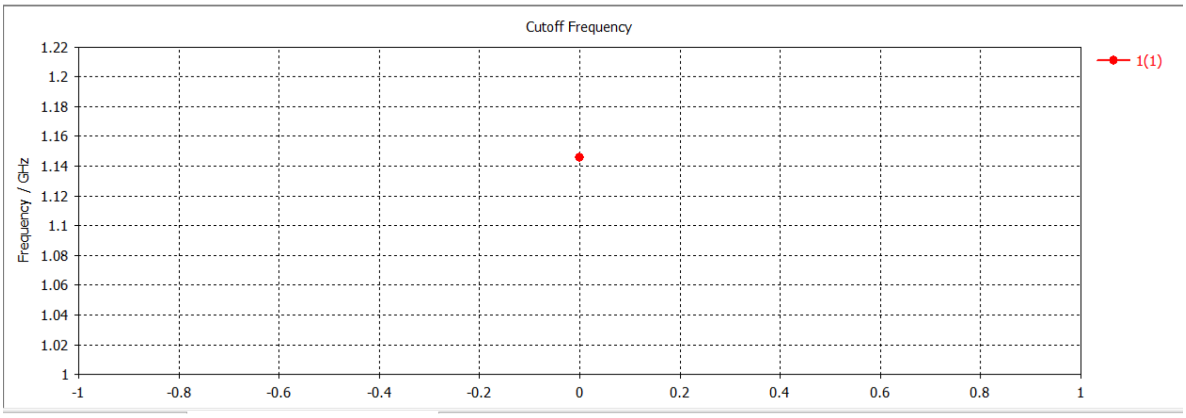


RESULTS:

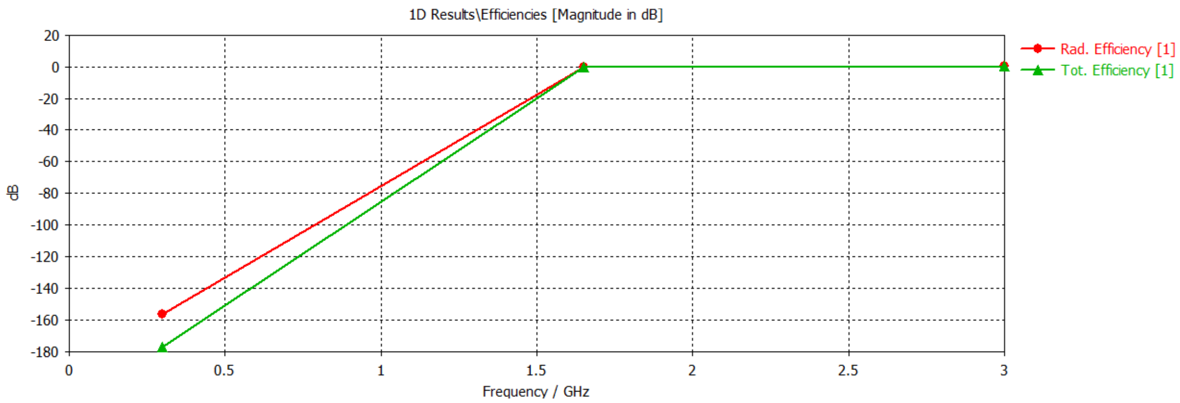
S-parameters:



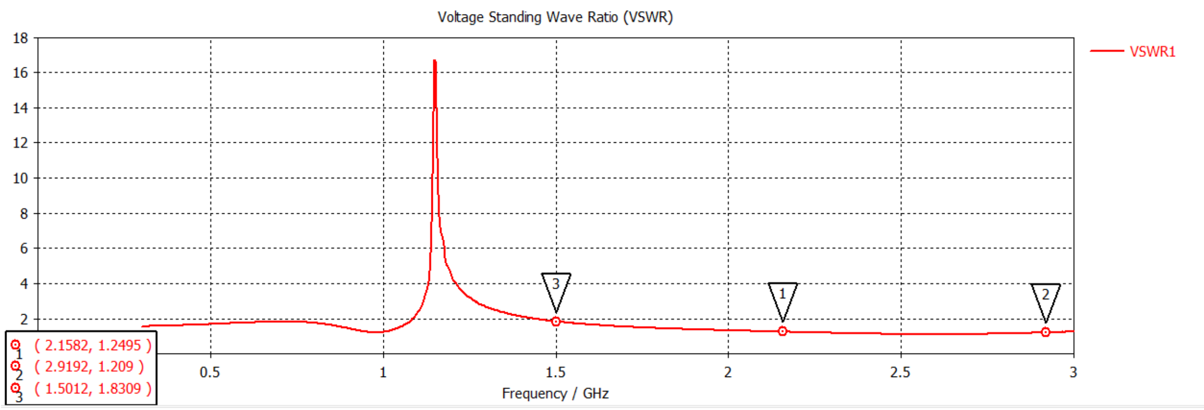
Port Cut-off Frequency (After changing distance of port from substrate to 10mm):



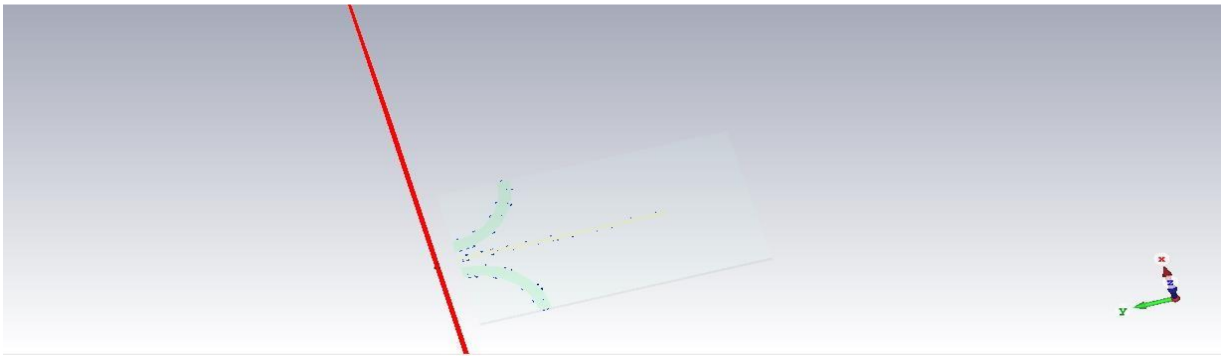
Radiation Efficiency:



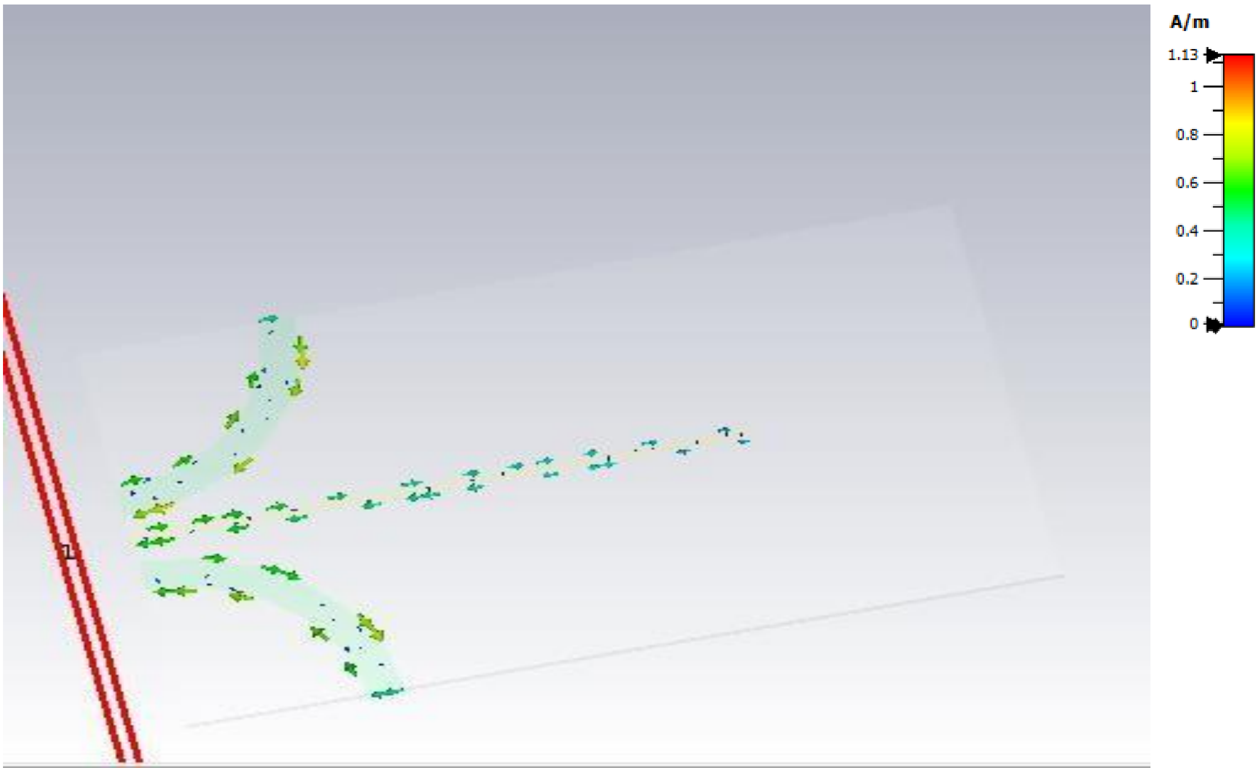
VSWR:



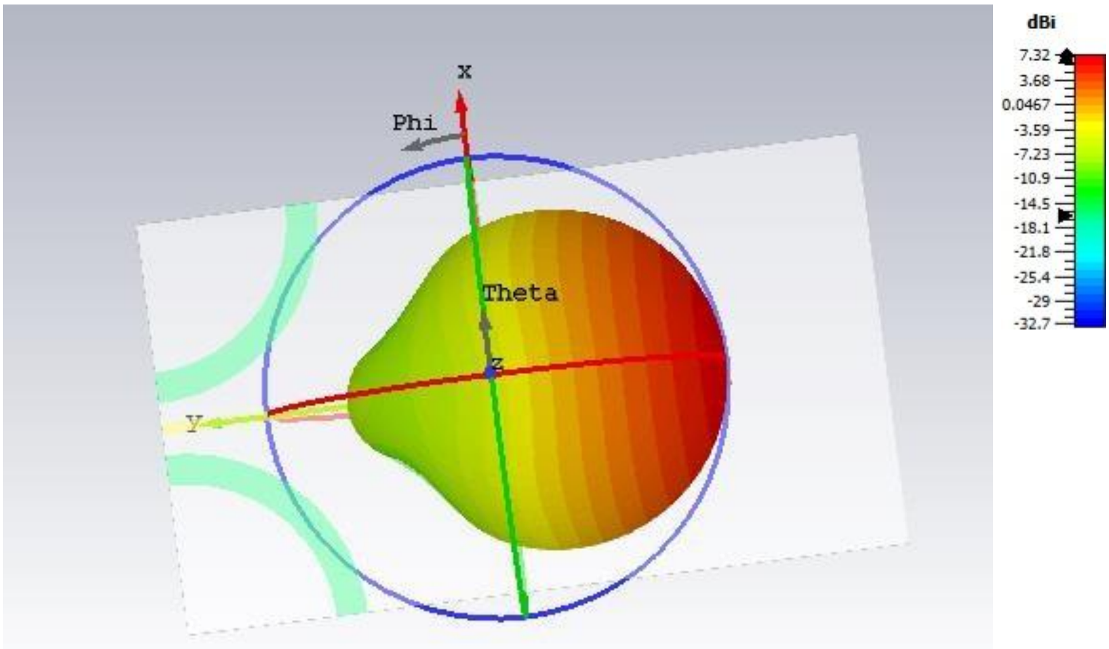
Surface Current Density at F = 0.3 GHz (Below Cut-off):



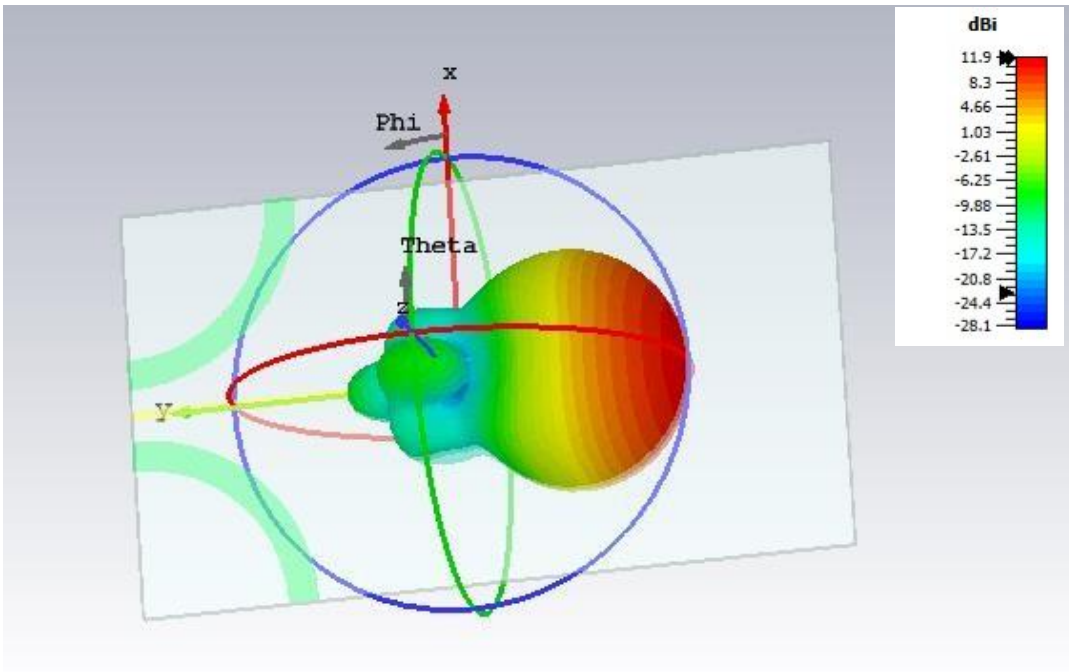
Surface Current Density at F = 1.65 GHz



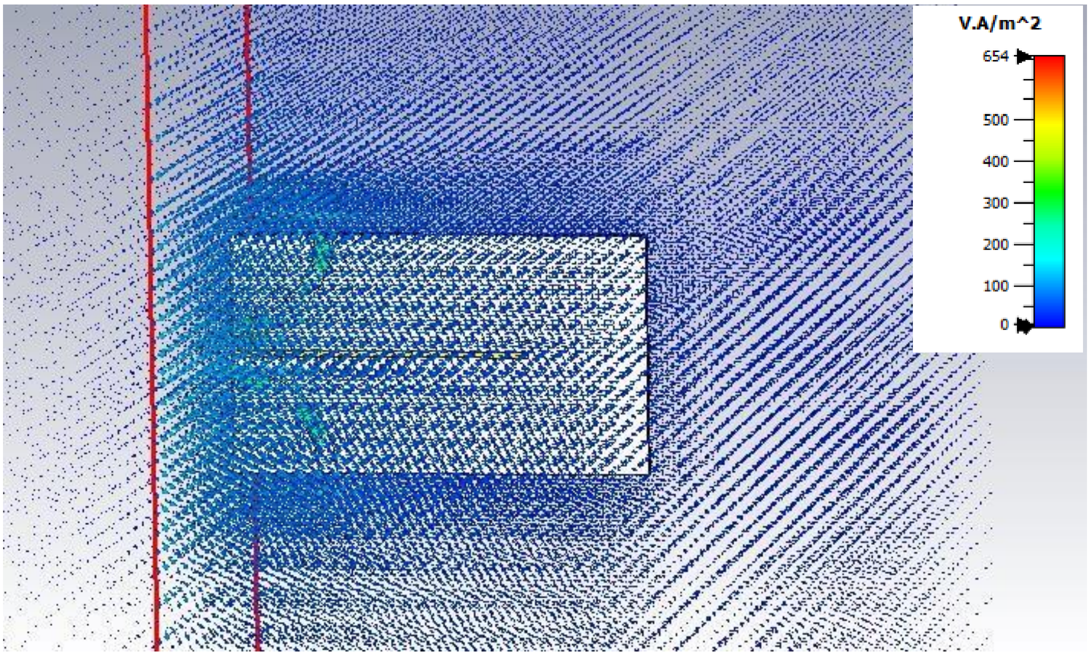
Farfield Abs Gain at F = 1.65GHz



Farfield Gain At F = 3GHz



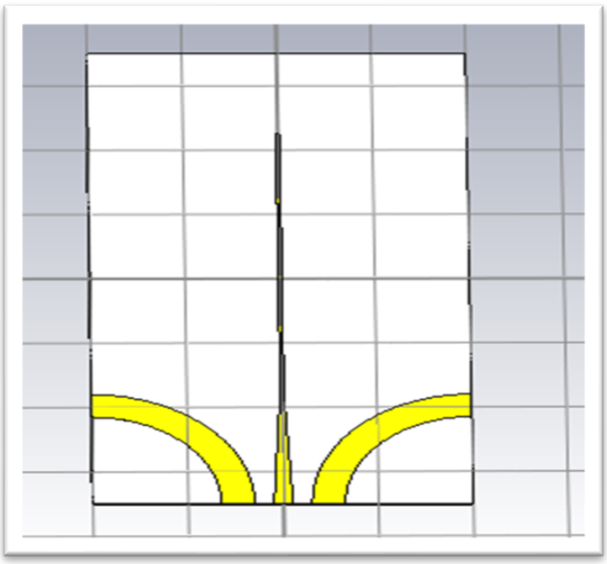
Power Flow At 1.65GHz



TRIAL 5 (Best of all trials):

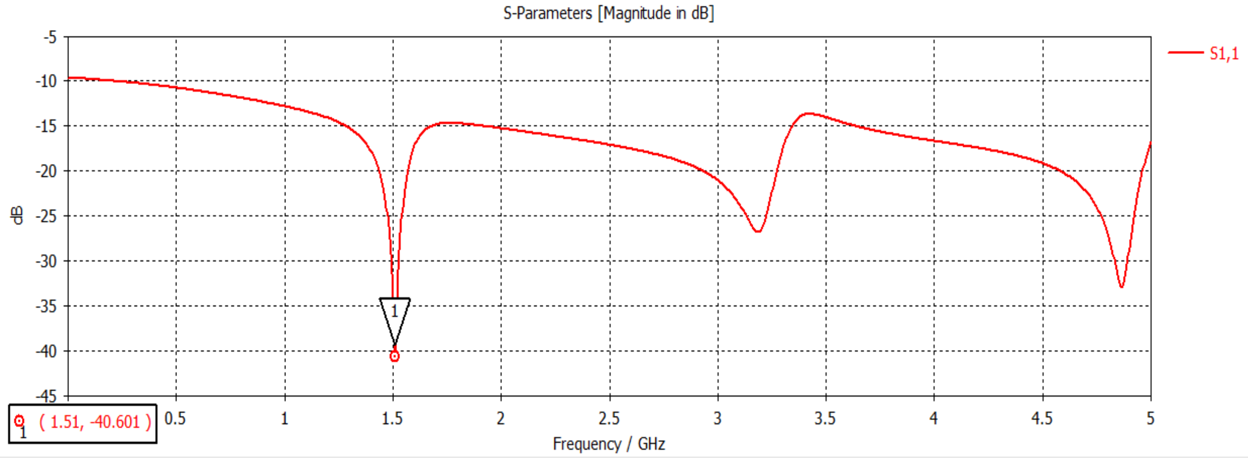
Model:

- Substrate Material: FR-4 Loss Free (Epsilon 4.3)
- Goubau Line and Parasitic plates material: Copper (annealed)
- Goubau Line base width changed from 1mm to 2mm and the end width changed from 1mm to 0.1mm. The width of G-Line decreases till it reached 0.1mm width.
- Quadrant ring inner radius – 13.5mm, outer radius – 17mm
- Port dimensions from centre of substrate – 5mm Width, 4mm height.

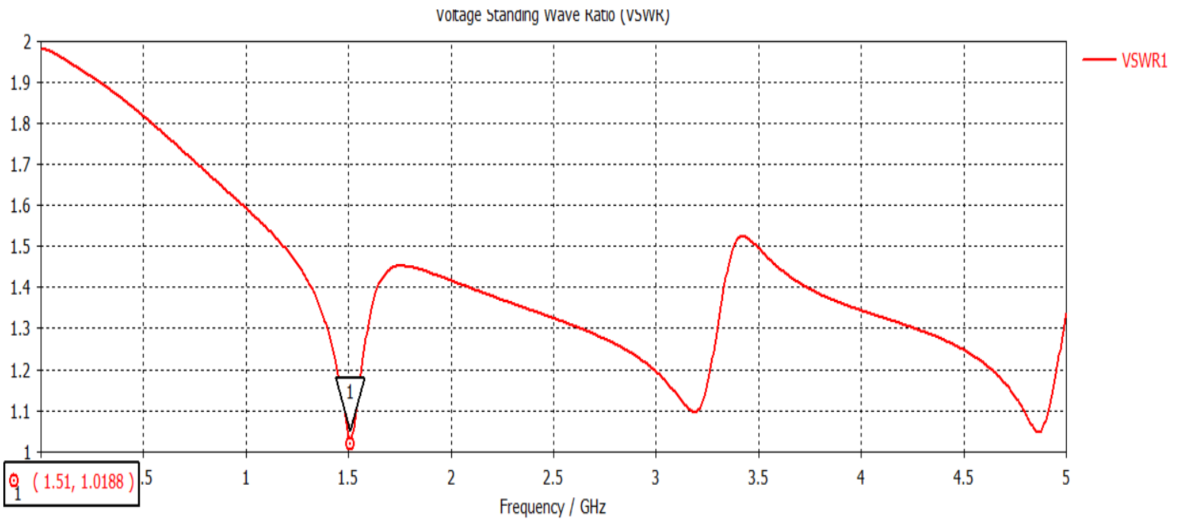


SIMULATION OBSERVATIONS:

S-parameter-

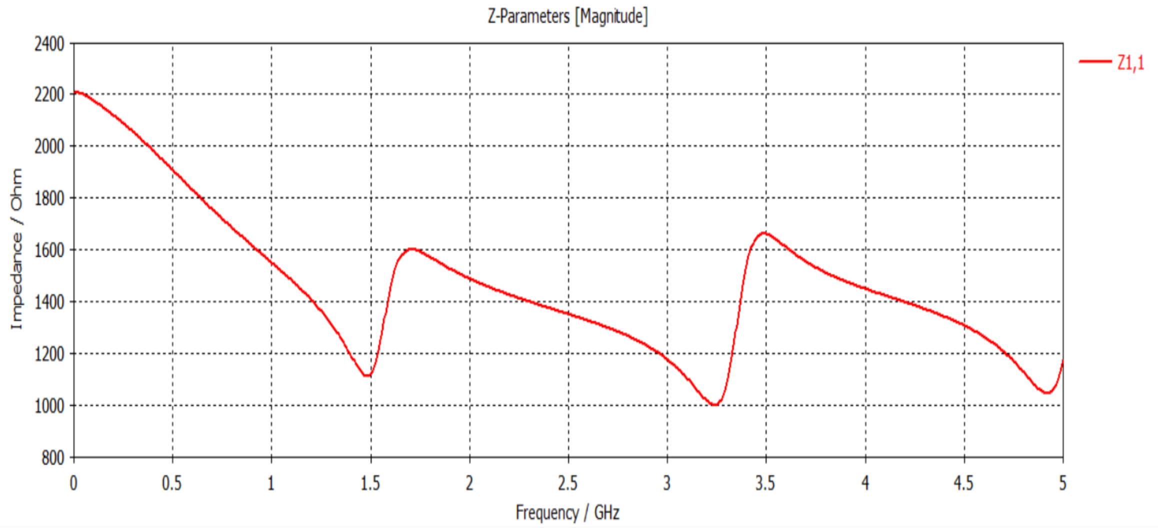


VSWR-

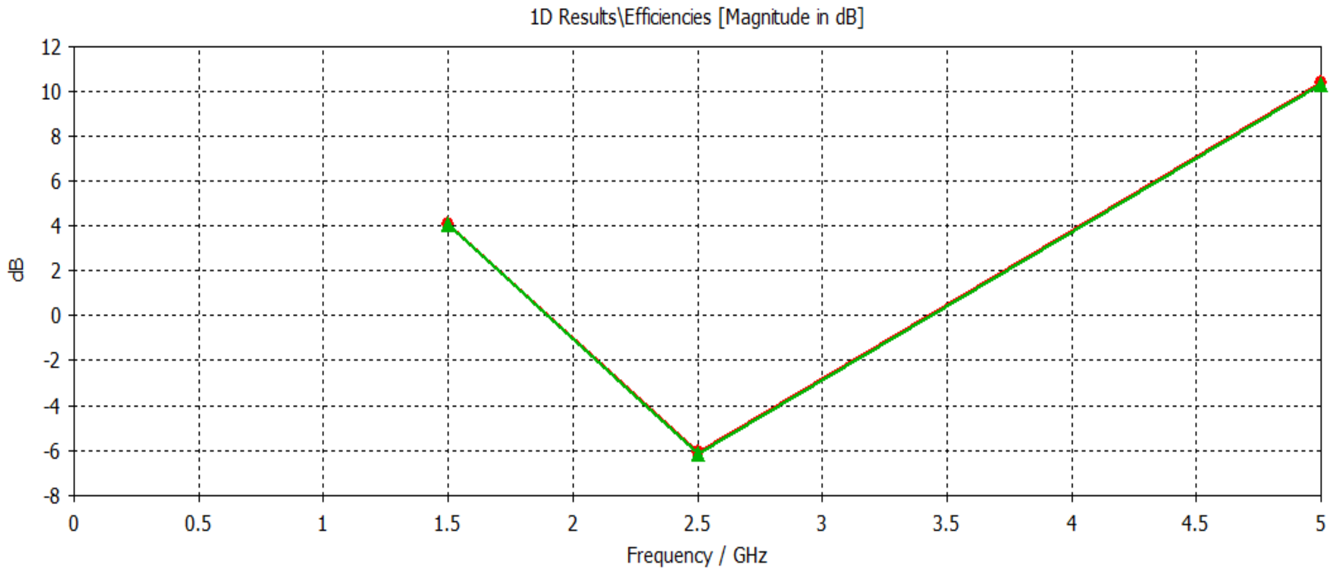


Here we can notice that VSWR traces the S-parameter and is between 1 and 2, which is a good sign

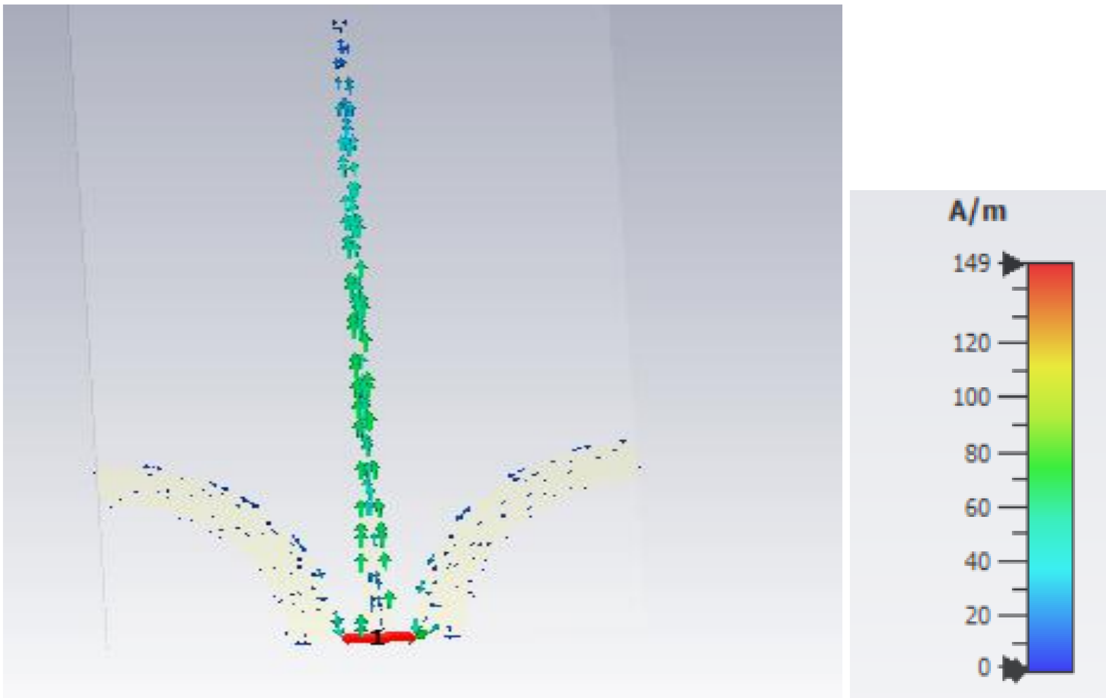
Z-Parameter-



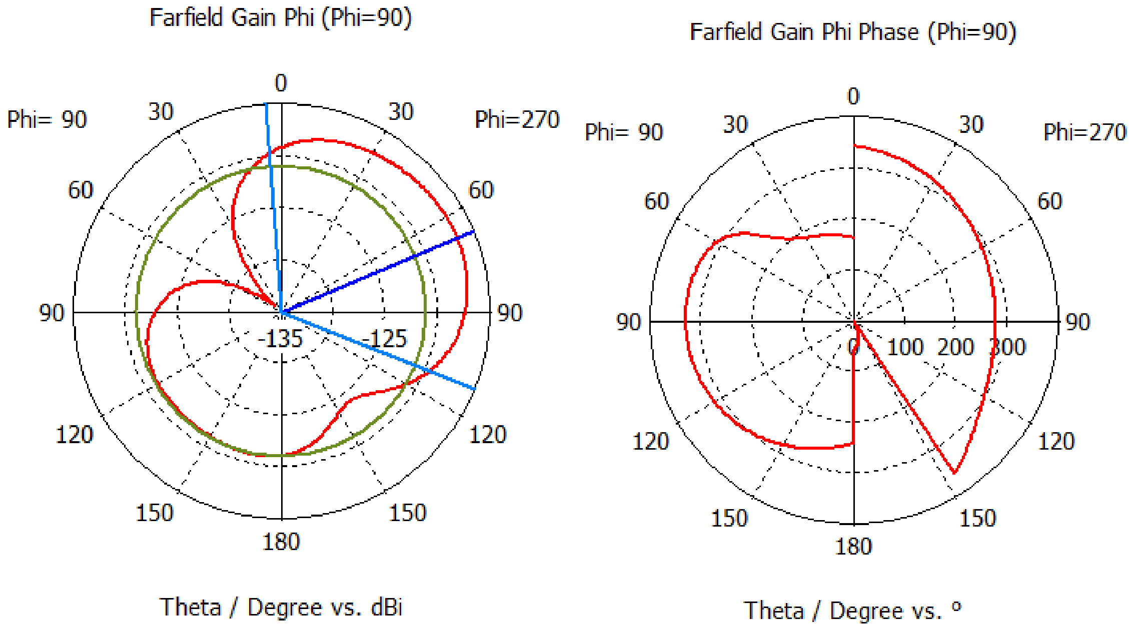
Radiation Efficiency-



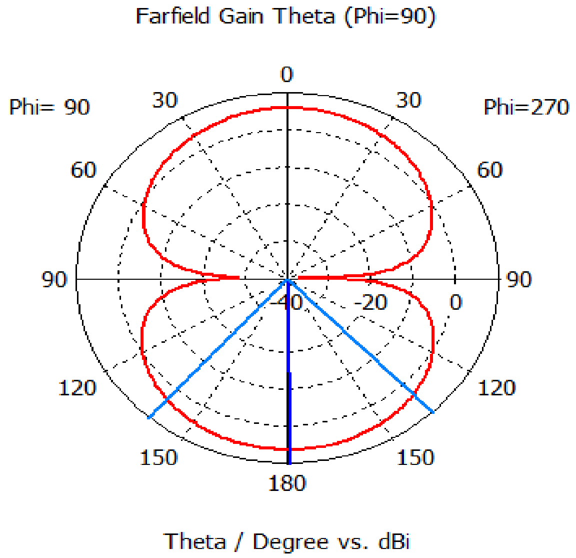
Surface Current (At 1.5GHz)-

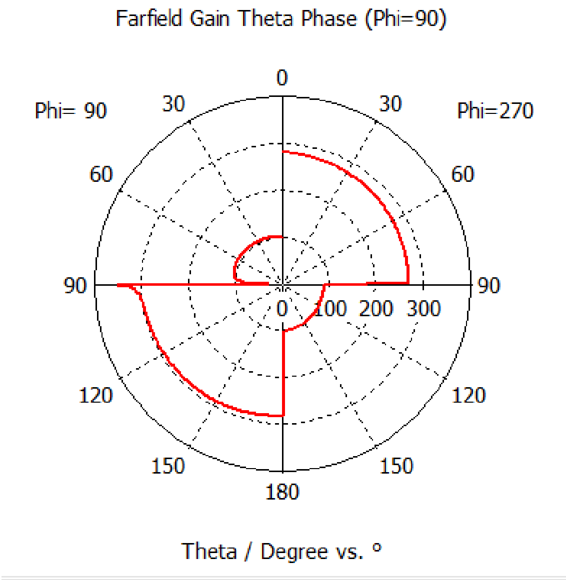


Farfield Gain Phi (Phi = 90) for 1.5GHz



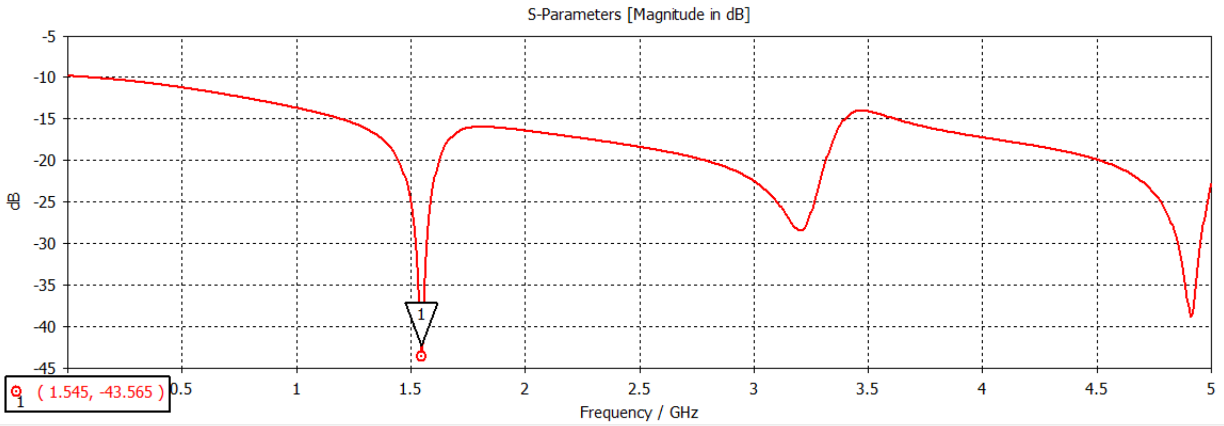
Farfield Gain Theta (Phi = 90) for 1.5GHz-





What if we increase the Goubau line port side width?

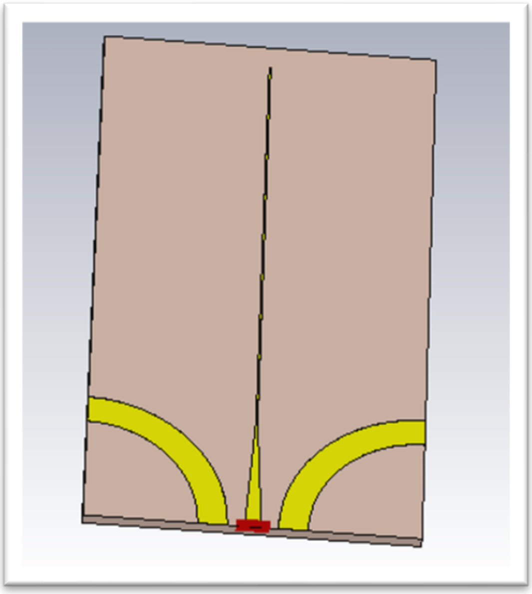
Changing the width, we can observe the following result. The S-parameter dip shifted by 0.4mm to 1.545mm as compared to the previous model where the dip was 1.5mm. Also, the minimum Magnitude goes down to -43.565 as compared to -40.601 in our previous model. Hence increasing the width will only make our PGL worse.



TRIAL 6:

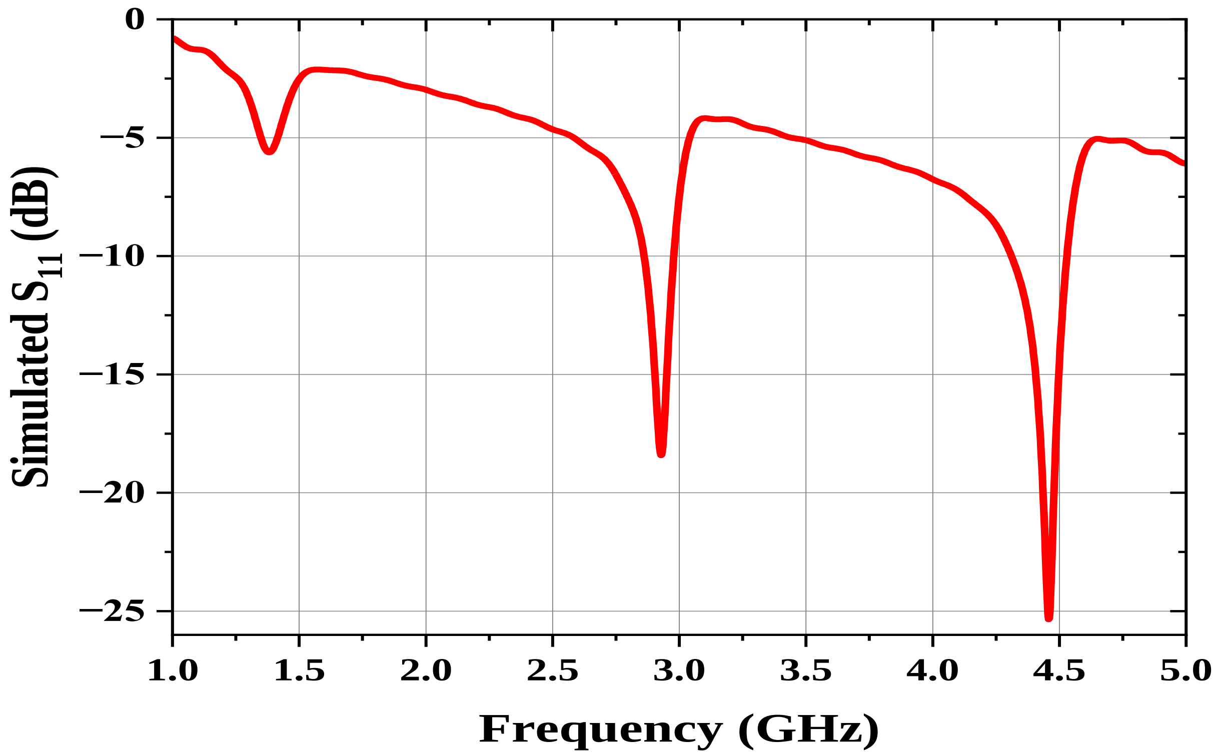
Although not best, let us use a G-Line that covers almost all the part of the substrate, (goes from -35cm to 25cm). **We will use this model as our fabrication model.** The width reduces from 2cm to 0.2cm. The rest parameters are similar to that of Model 5.

MODEL:

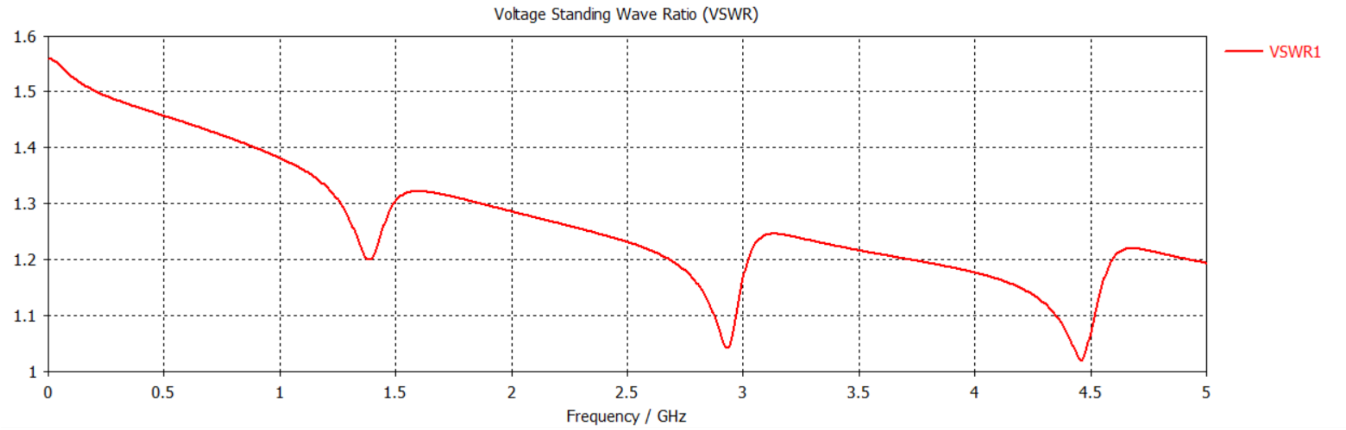


SIMULATION OBSERVATIONS:

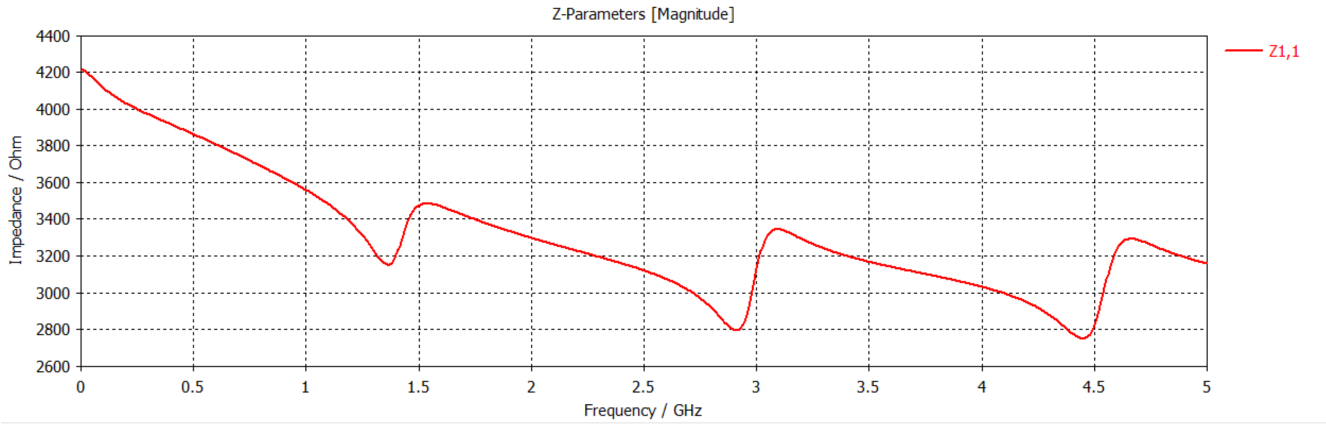
S-parameter-



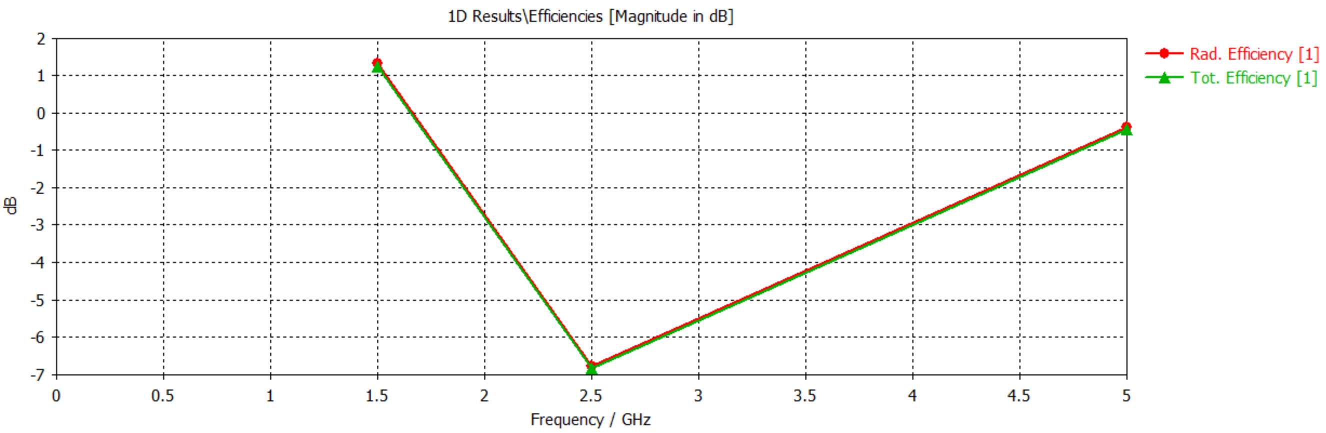
VSWR-



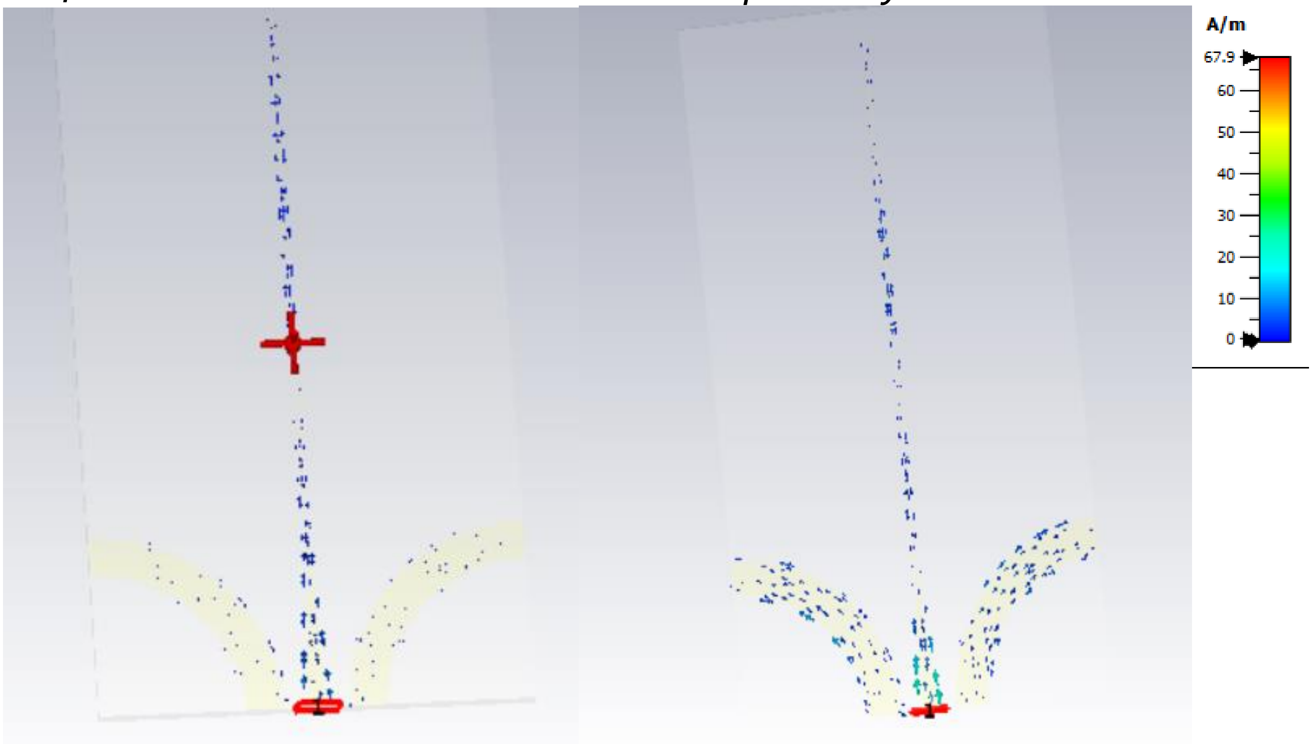
Z-Matrix-



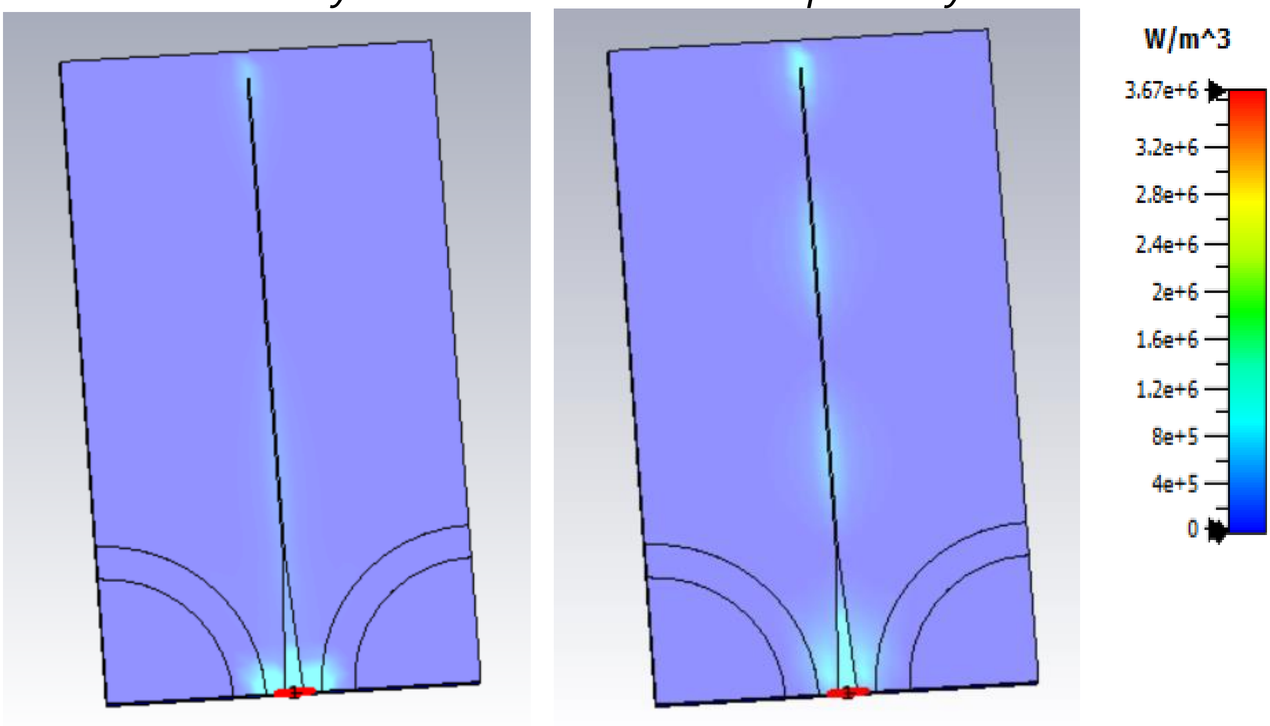
Radiation Efficiency-



Surface Current at 2.5GHz and 5GHz respectively-

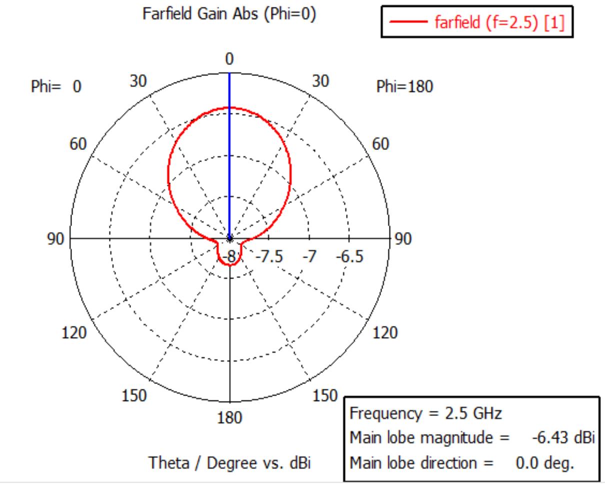


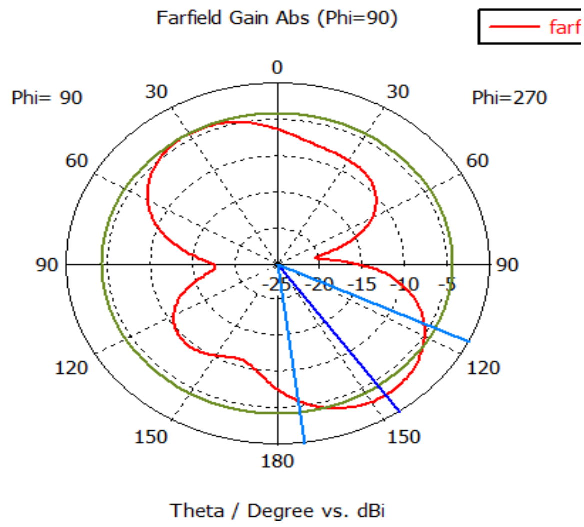
Power Loss Density at 2.5GHz and 5GHz respectively-



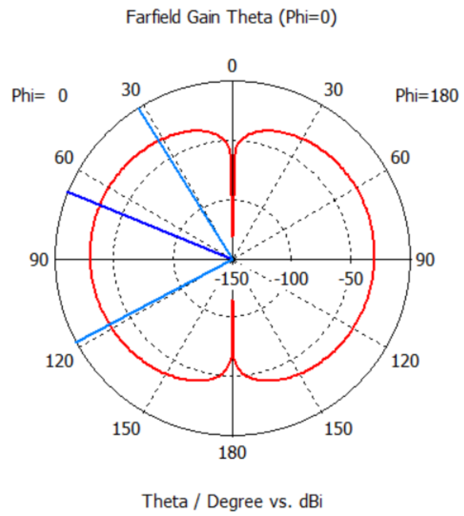
Farfields for Freq = 2.5GHz

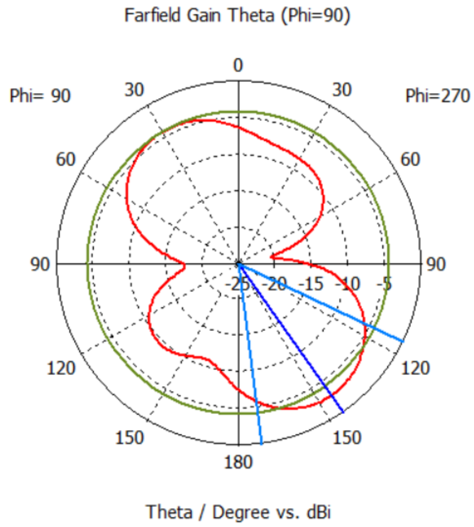
Farfield Gain Abs (Phi = 0, 90)

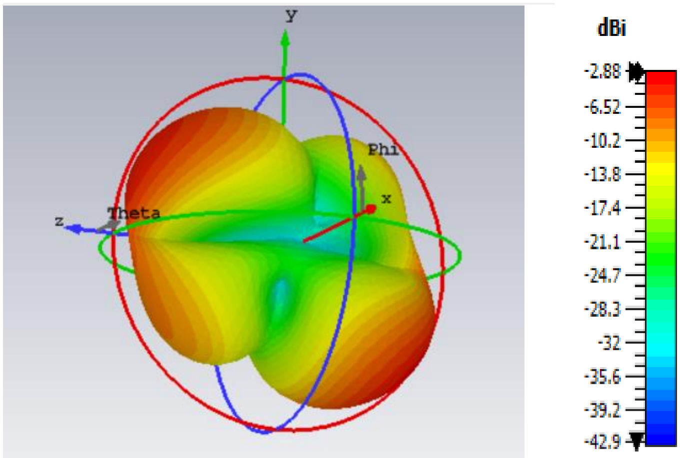




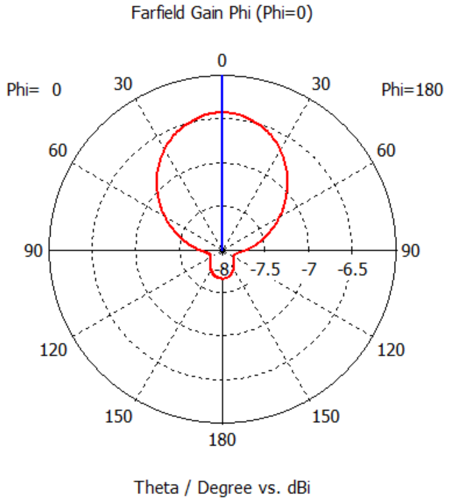
Farfield Gain Theta (Phi = 0, 90)

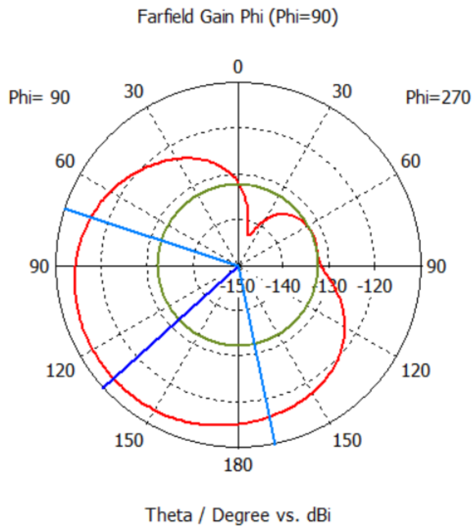


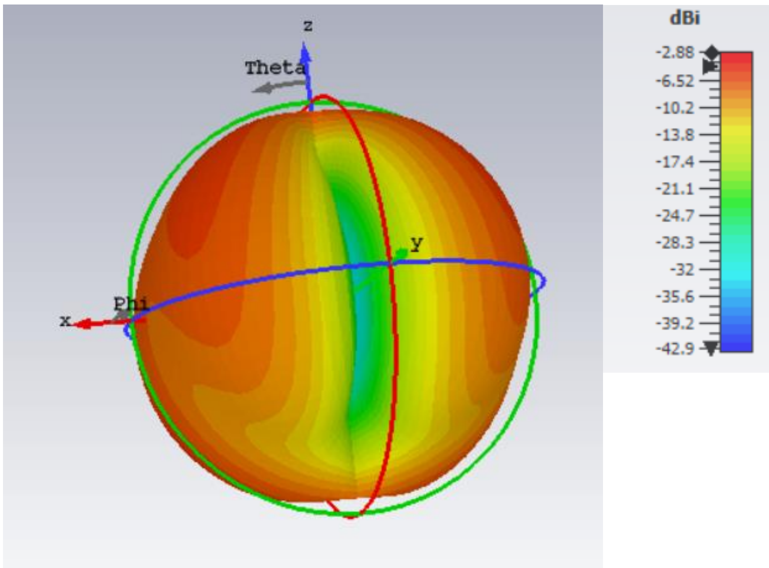




Farfield Gain Phi (Phi = 0, 90)

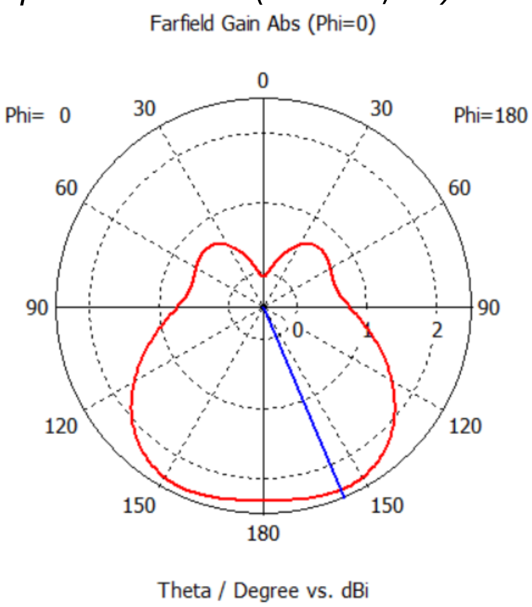


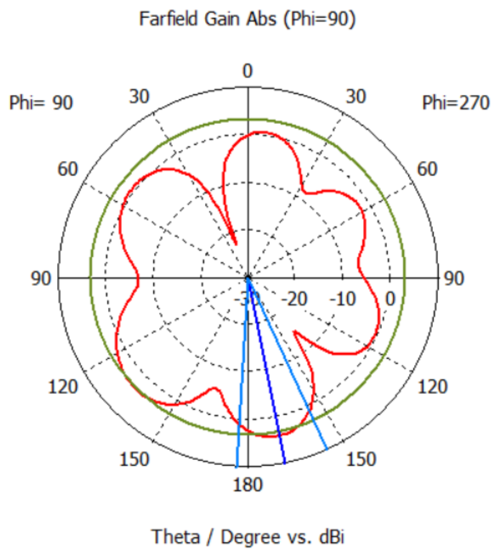




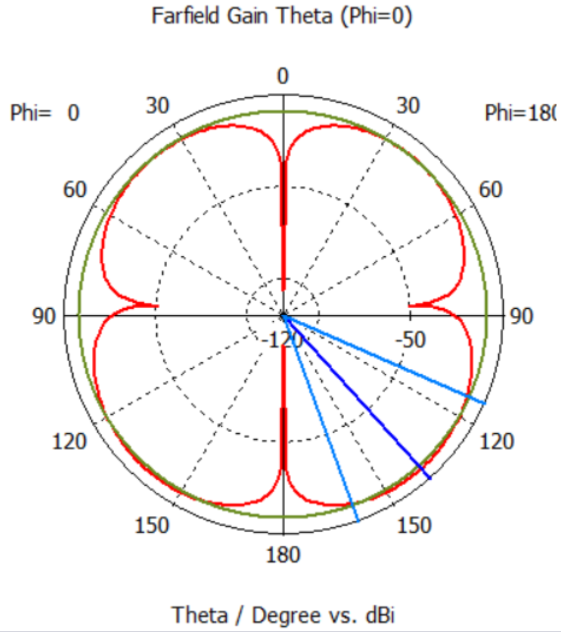
Farfields for Freq = 5GHz

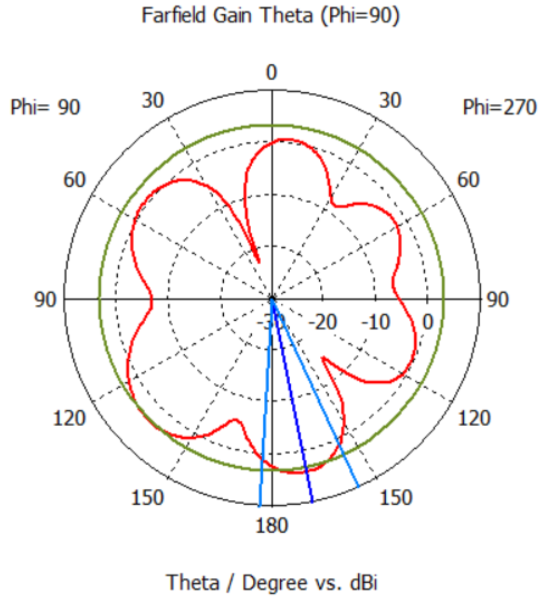
Farfield Gain Abs (Phi = 0, 90)

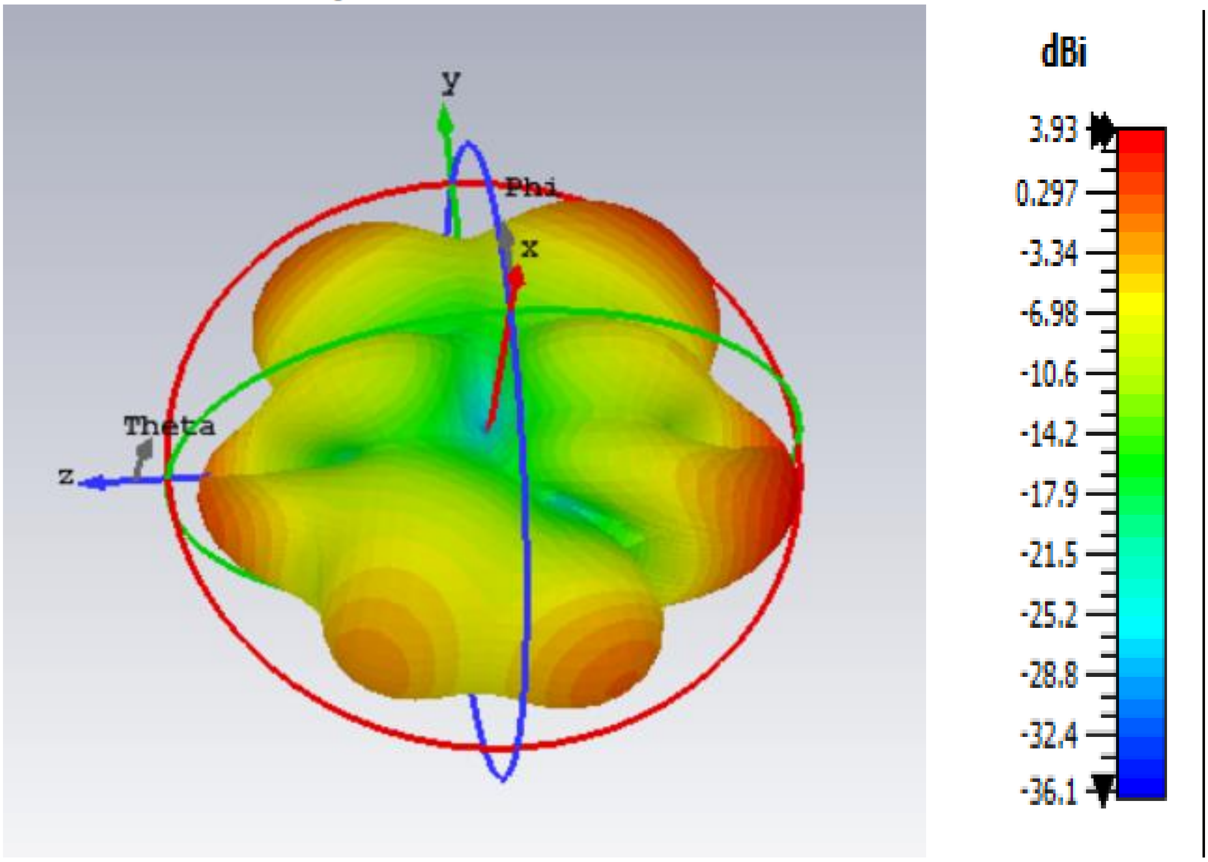




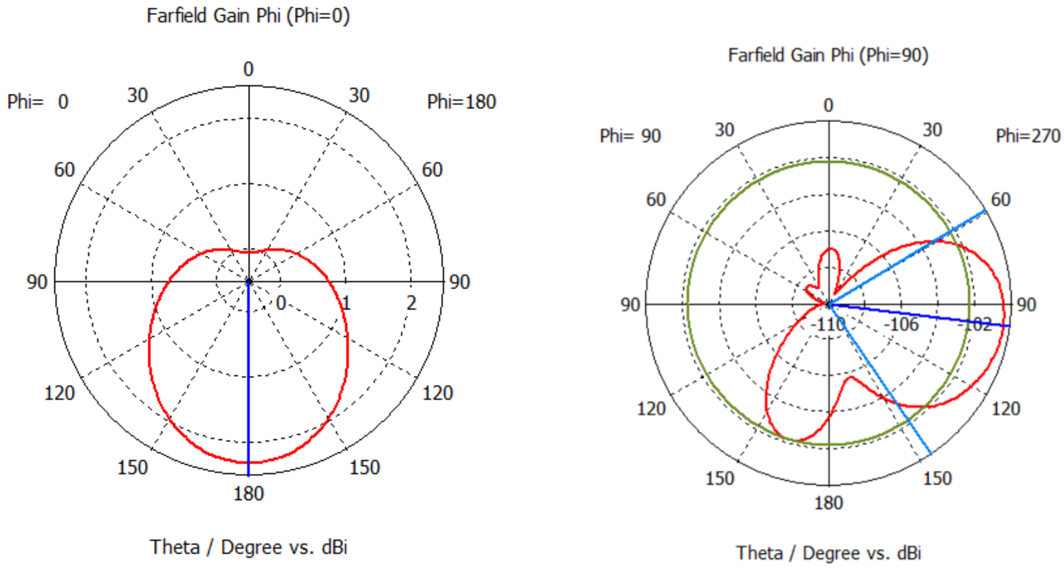
Farfield Gain Theta (Phi = 0, 90)

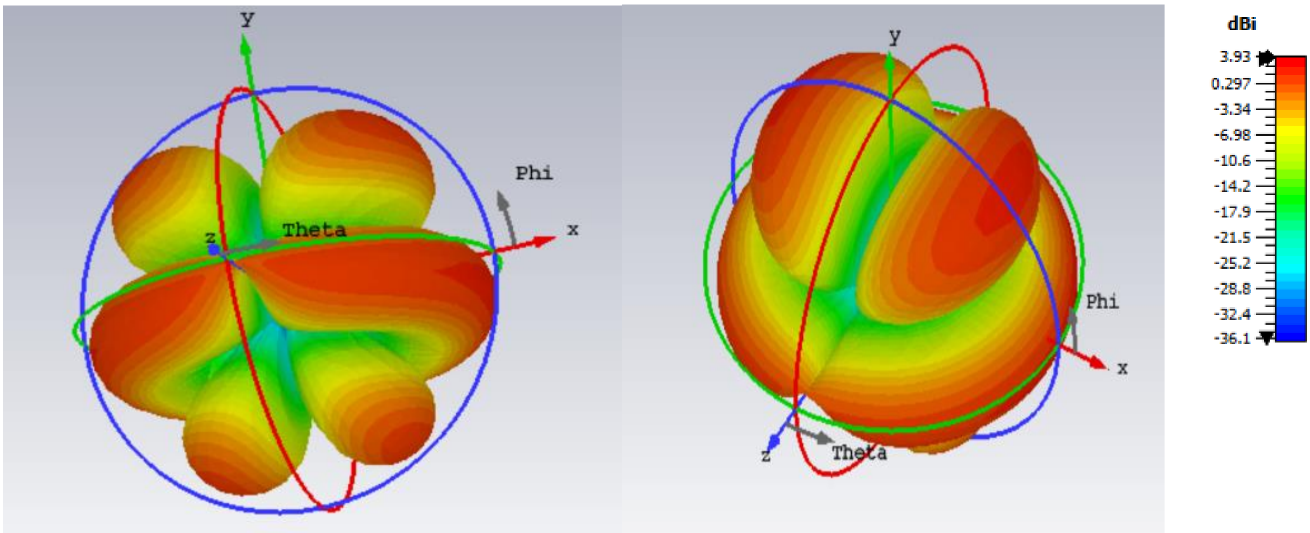






Farfield Gain Phi (Phi = 0, 90)





FABRICATION:

The term fabrication of antennas refers to the process of physically manufacturing or constructing antennas, devices used for transmitting or receiving electromagnetic waves. The fabrication process involves several steps, which can vary depending on the type of antenna and the materials used.

Here is a general overview of the fabrication process used in the design of our PGL Antenna:

- **<u>Substrate preparation</u>:** The antenna designed is to be printed on a substrate, which needs to be prepared first. This involves cleaning the substrate surface, then cutting it into dimensions of 70 * 40 mm which is in accordance to our antenna design and ultimately filing the substrate to ensure its flatness and uniformity.

FIG. 1: FR-4 SUBSTRATE (EPSILION = 4.3)

- The next step involves obtaining the dxf file of our antenna design (from CST Studio), and then printing the dxf file on a white paper with the help of a CAD Tool. This is done to verify the dimensions used for our antenna design. After verifying we print the final dxf file on a transparent sheet. We call it the photomask in the photolithography process.

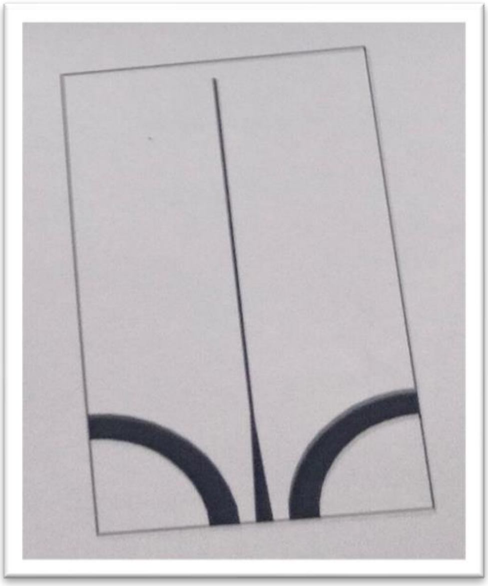


FIG. 2: DXF PRINT ON WHITE PAPER AND TRANSPARENT PAPER (PHOTOMASK)

- Next, we are cleaning the cut substrate with acetone, which acts as a powerful solvent and can effectively remove contaminants like oil, dirt, and other organic residues. Acetone is also compatible with materials commonly used in antenna fabrication, has a low boiling point and evaporates quickly at room temperatures minimizing the risks of prolonged process time.
- Following this, we start the process of *Photolithography.* Photolithography involves transferring a pattern from a photomask onto our substrate coated with photosensitive material (photoresist) to create intricate antenna patterns. UV light is used to expose the photoresist, initiating a chemical reaction that allows for the creation of the desired pattern. Performing this process in a dark room minimizes unwanted exposure to ambient light, which could interfere with the precise patterning. The Substrate was placed in a box that emitted UV light and placed in it for exactly 17 minutes so that the photoresist is developed and a patterned layer is present. *Placing for more than 17 minutes or less can result in inconsistent pattern to be developed on our substrate.*

FIG. 3A: UV BOX WHERE SUBSTRATE WITH PHOTORESIST IS KEPT FOR 17 MIN.

FIG. 3B: LIGHT SHIELDED ROOM TO GET SOME DEGREE OF VISIBILITY.

- Next, we go for wet etching of the antenna. This process involves using of chemicals *(hydroxides (e.g., KOH, CsOH), tetramethylammonium hydroxide ethylenediamine, pyrocatechol, Hydrogen Fluoride, Nitric acid, Acetic acid (HNA), amine gallate and hydrazine-water)* to remove the layers of metal on substrate besides the developed pattern. The liquid was consistently moved through the substrate in a tub so that we get an even removal of the copper plate on top of the substrate.

FIG. 4: WET ETCHING PROCESS.

- The remaining copper that is not required on the substrate, is removed by applying acetone. Also in-case of any discontinuity, we apply *silver paste* to fix it. Sometimes, the result will vary because manually we cannot get to the best precision level but in most cases the measurement result will be very close to the desired result. A multi-meter is used to check the discontinuity of our PGL antenna.

- Finally, we attach a feed (placed only on G-Line since *parasitic couplers were shorted* if it was attached on them) on our substrate after finalizing the structure of our antenna. In our case we put a CPW feed on top of our G-Line and use silver strips to solder the CPW feed on our Antenna.

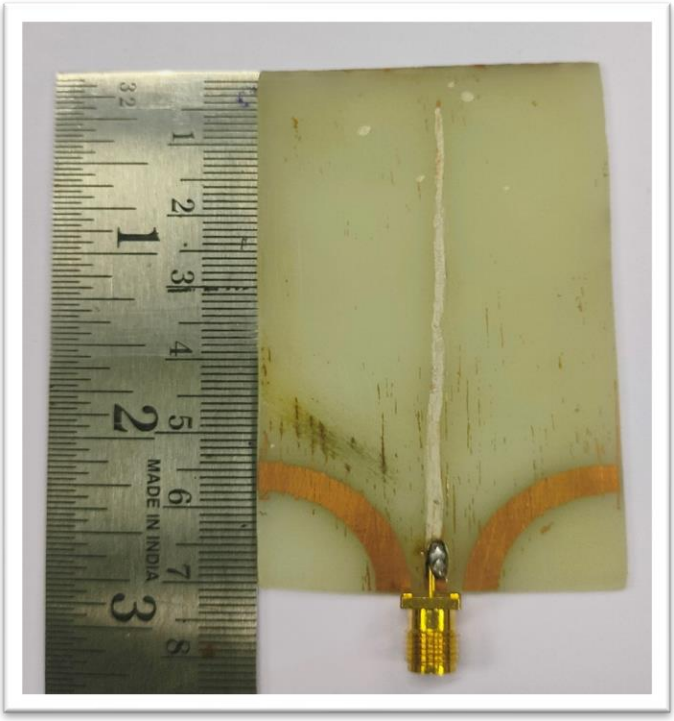


FIG. 5A: FRONT VIEW OF ANTENNA AFTER ATTACHING THE CPW PORT/FEED.

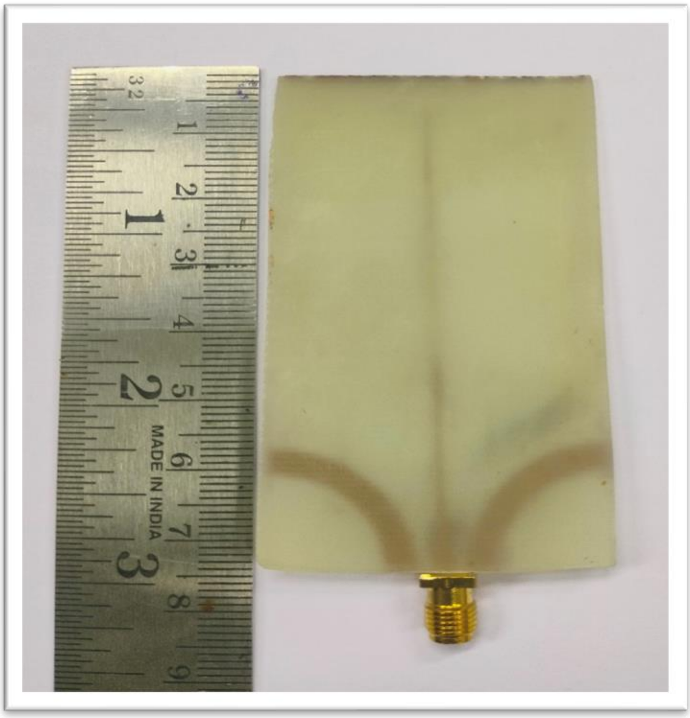


FIG. 5B: BACK VIEW OF ANTENNA AFTER ATTACHING THE CPW PORT/FEED.

The above antenna is now ready for measurement (of S_{11}).

MEASUREMENT:

By measurement we are mainly concerned about the *S_{11} or the return loss or the reflection co-efficient*. The return loss of a Goubau line antenna refers to the amount of power that is reflected back from the antenna due to impedance mismatch. It is an important parameter that indicates the efficiency of power transfer between the transmission line and the antenna.

To measure the return loss of a Goubau line antenna, you would typically use a *vector network analyzer (VNA)* or *a network analyzer*. Show below is the general procedure for measuring the return loss:

- Connect the Goubau line antenna to the network analyzer. Ensure that the connection is secure and properly matched.
- Configure the network analyzer to measure the S_{11} parameter, which represents the reflection coefficient of the antenna. S_{11} is a complex number that consists of both magnitude and phase information.
- Set the frequency range and resolution on the network analyzer based on the desired measurement bandwidth.
- Initiate the measurement and record the S_{11} data. The network analyzer will sweep through the specified frequency range and measure the reflection coefficient at each frequency point.
- Convert the reflection coefficient to return loss, which is typically expressed in decibels (dB). Return loss (RL) can be calculated using the following formula: **RL (dB) = 20 * log10($|S_{11}|$)**

  Where |S11| represents the magnitude of the reflection coefficient.
- Plot the return loss versus frequency to visualize the performance of the Goubau line antenna over the measured bandwidth.

By analysing the return loss measurement, we can determine the frequency range over which the Goubau line antenna exhibits good impedance matching and low reflection. A lower return loss value indicates better matching and less power being reflected back towards the source.

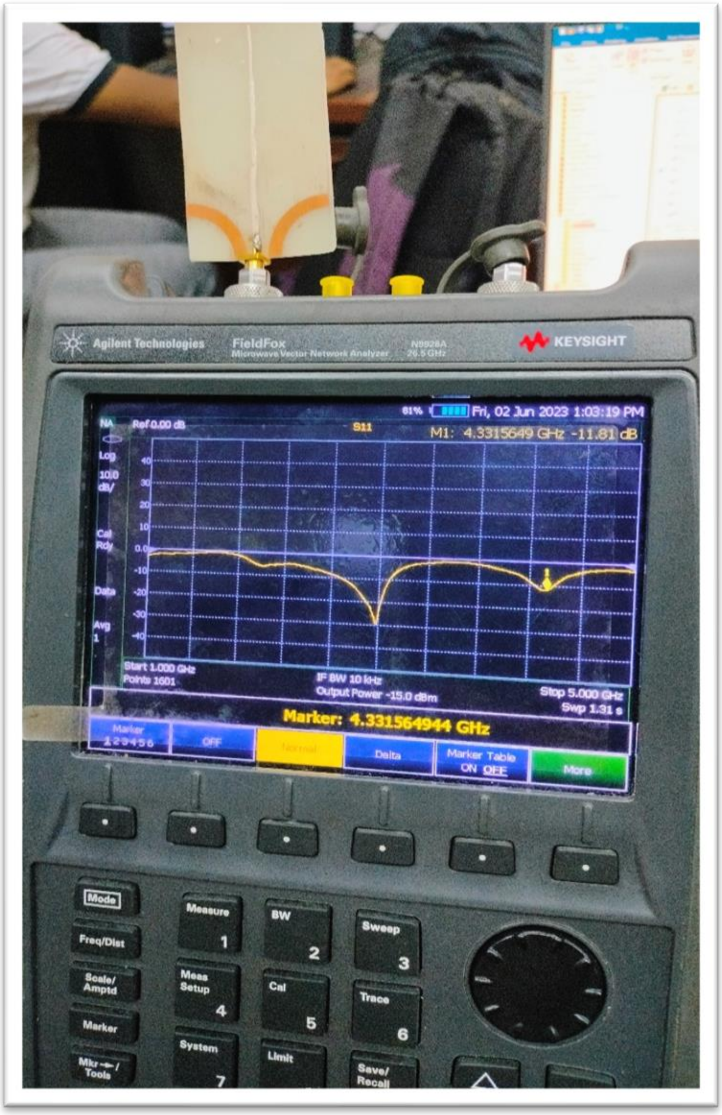
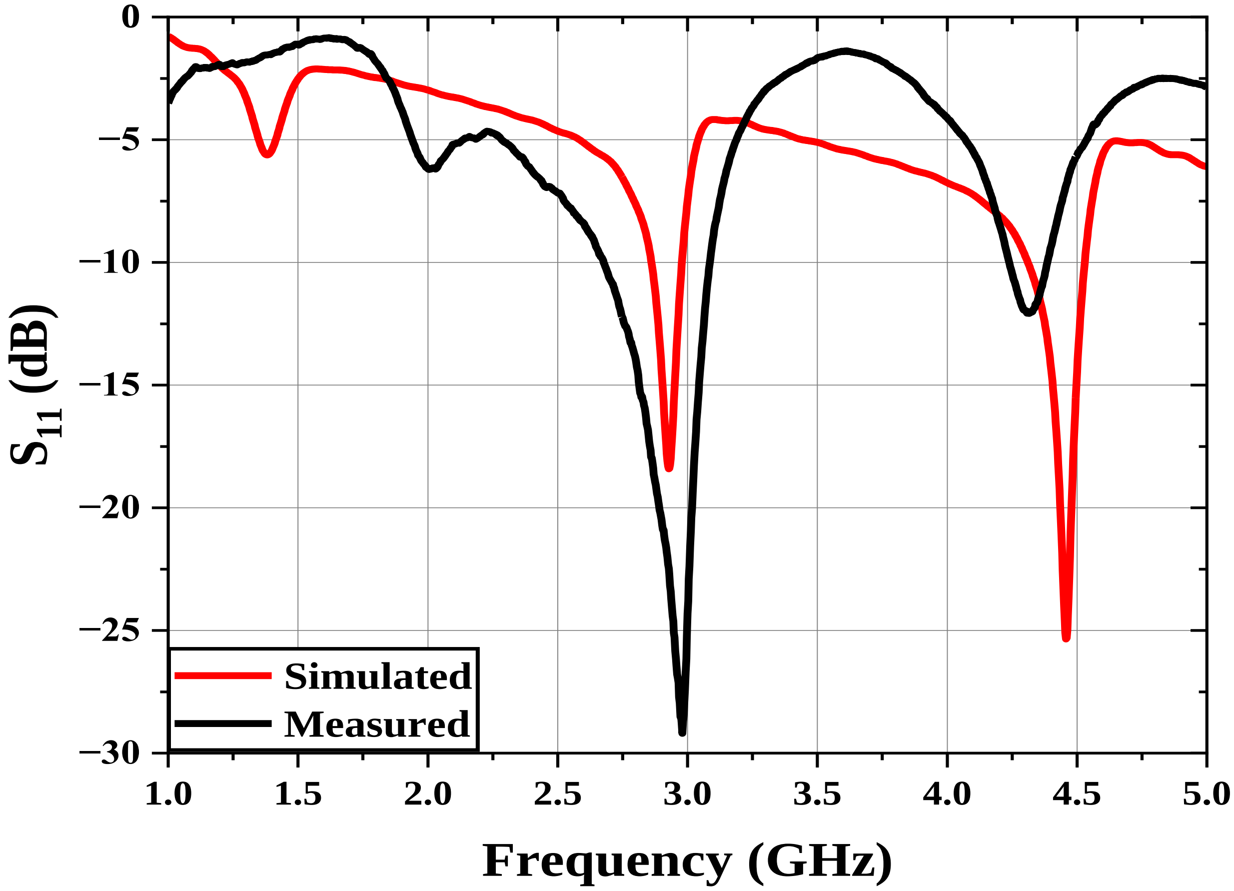


FIG. : S_{11} MEASUREMENT AS SEEN ON VECTOR NETWORK ANALYZER

TABLE ON FEW RETURN LOSS DIPS:

	Freq. 1	S_{11} 1	Freq. 2	S_{11} 2
Simulation	2.93	-18.41	4.46	-25.3
Measurement	2.97	-29.20	4.32	-22.1

SIMULATED VERSUS MEASURED S_{11}



CONCLUSION ON THE REPORT:

We learned about different types on antenna and also the reason why anisotropic materials are used for our Goubau line antenna.

We also learned how changes in materials can drastically affect our results. When we used Rogers Compound in CST, it gave different result as compared to the same using FR-4. Changes in our couplers resulted in different result as well (the ring quadrant gave sharper return loss as compared to when we had the whole quadrant coupler or couplers on both end of G-Line). We also see the length of the G-Line is directly dependent on the coupler. If we have really long G-Line, the result will not be as good as a G-Line with subsequently shorter length. We need an optimum length of PGL to ensure the couplers work at their best capacity as seen from TRIAL 5 and TRIAL 6.

Finally, we also did the fabrication process which helped us get a gist of the world of antenna fabrication. We could almost trace the measurement and simulated result using the Origin software hence ensuring best results in the fabrication. There has been small differences in our result because of the manual usage of silver paste which increased the thickness of G-Line, although discontinuity after the etching process is not that easy to avoid, we can prepare a darker mask which could have given us better results.

REFERENCES:

[1] Abrar Hakim and UmarKhayam, “Design of Planar Goubau Line Antenna for Partial Discharge Measurement,” in The 3rd IEEE Conference on Power Engineering and Renewable Energy ICPERE 2016.

[2] T. Akalin, E. Peytavit, and J. F. Lampin, "Bendings and Filters with Single Strip THz Plasmonic Wavegnides", 2007 Joint 32nd International Conference on Infrared and Milli-meter Waves and the 15th International Conference on Terahertz Electronics (IRMMW-THz). pp. 75-76, 2007.

[3] Xiao-Lan Tang, Qingfeng Zhang, Sanming Hu, ShangkunGe, YifanChen & HaoYu, “Beam Steering Using Momentum Reconfgurable Goubau Meta-Line Radiators,” Aug. 07 2016.

[4] Goubau, G. Open wire lines. IRE Trans. Microw. Theory Tech, 197–200 (1956).

[5] Goubau, G. Surface waves and their application to transmission lines. J. Appl. Phys, 1119–1128 (1950).

[6] Tahsin Akalin, Anthony Treizebré, and Bertrand Bocquet, “Single-Wire Transmission Lines at Terahertz Frequencies,” in IEEE Transactions on Microwave theory and techniques, vol. 54, NO. 6, JUNE 2006.

[7] D. Gacemi, J. Mangeney, R. Colombelli & A. Degiron, “Subwavelength metallic waveguides as a tool for extreme confinement of THz surface waves,” in Institut d’Electronique Fondamentale, Univ. Paris Sud, UMR CNRS 8622, 91405 Orsay, France, Dec.–March. 13-6, 2012-2013.

[8] K. Wang and D. M. Mittleman, “Metal wires for terahertz wave guiding,” Nature, vol. 432, pp. 376–379, Nov. 2004.

[9] G. Zheng, J. Papapolymerou, and M. M. Tentzeris, “Wideband coplanar waveguide RF probe pad to microstrip transitions without via holes,” IEEE Microwave Wireless Compon. Lett., vol. 13, no. 12, pp. 544–546, Dec. 2003.

[10] Anthony Treizebre´ , Bertrand Bocquet, Yansheng Xu, and Renato G. Bosisio, “New THz Excitation of Planar Goubau Line” in DOI 10.1002/mop Microwave and Optical Technology Letters / Vol. 50, No. 11, November 2008

[11] T. Akalin, A. Treizebré, N. E. Bourzgui, and B. Bocquet, “THz microfluidic MEMS for cell membrane analysis,” in IEEE 12th Int. Terahertz Electron. Conf., Karlsruhe, Germany, Sep.–Oct. 26–1, 2004, pp. 413–414.